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HELIOCENTRIC INTERPLANETARY LOW THRUST  
TRAJECTORY OPTIMIZATION PROGRAM

Supplement # 1

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## SUMMARY

This report is the first supplement to the primary HILTOP program document published in January, 1973, and describes the modifications and improvements made to the HILTOP electric propulsion trajectory optimization computer program up through the end of 1974.

New program features include the simulation of power degradation, housekeeping power, launch asymptote declination optimization, and powered and unpowered ballistic multiple swingby missions with an optional deep space burn.

The report contains the new analysis describing these features, a complete description of program input quantities, and sample cases of computer output illustrating the new program capabilities.

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## I. INTRODUCTION

This document describes the modifications and improvements made to the HILTOP electric propulsion trajectory optimization computer program [1] during calendar years 1973 and 1974. New program features include the simulation of power degradation, housekeeping power, launch asymptote declination optimization, and powered and unpowered ballistic multiple swingby missions with an optional deep space burn.

The power degradation model has been hypothesized by the authors in earlier publications [2, 3]. The model allows a single parameter (denoted "characteristic degradation time") to describe the power degradation behavior of an electric propulsion spacecraft to a degree which fundamentally affects the solution to the trajectory optimization problem.

The option of simulating spacecraft housekeeping power applies to solar electric propulsion with specified reference power. The housekeeping power is a specified constant power generated by the solar arrays and shunted away from the thruster power-conditioners and directly to the spacecraft payload for "housekeeping" purposes.

The launch asymptote declination optimization model was first hypothesized by the authors in the appendix of [1], and later a more thorough treatment of the subject was put forth in [4]. A solution to the problem of optimizing electric propulsion heliocentric trajectories, including the effects of geocentric launch asymptote declination on launch vehicle performance capability, is developed using variational calculus techniques. The model of the launch vehicle performance includes a penalty associated with a non-easterly launch plus another penalty arising from a non-coplanar launch from the parking orbit. Provisions for range safety constraints are included. Optimal trajectories will generally have the launch excess velocity offset from the initial primer vector.

Extra-ecliptic mission simulations now involve launches from the Earth in which the Earth's ephemeris is generated by the program's analytic ephemeris capability; previously, extra-ecliptic missions were generated simply by starting the trajectory on the x-axis at one astronomical unit from the sun. This improved extra-ecliptic capability allows the launch date to be optimized together with the launch asymptote declination. Also, an additional set of boundary conditions has been added to the program for simulating extra-ecliptic missions.

The program's ability to simulate all-ballistic missions has been expanded to include powered and unpowered multiple swingby missions with an optional deep space burn. This capability renders HILTOP a powerful tool for ballistic mission design and optimization, with tremendous flexibility for creating imaginative multi-target mission profiles.

This report contains the analysis describing these new program features, a complete description of program input quantities, and sample cases of computer output illustrating the new program capabilities.



## II. FORMULATION

### A. SPACECRAFT AND TRAJECTORY MODELS

The assumed spacecraft and trajectory models are as described in [1] and are not repeated here; the nomenclature used in the following analysis is also described in [1], except for the introduction of new symbols which are described in the text as they appear.

1. Power Degradation. Historically, this electric propulsion power degradation model first appeared in the literature in [2], and then soon afterward an improved discussion appeared in [3], in which several of the ramifications and consequences of the theory are also discussed. For deeper insight into the analysis, the reader is therefore referred to [3], from which much of the analysis below is extracted.

The model discussed here is concerned with the manner in which the performance of a solar array degrades due to high energy particle damage. It is assumed that one can define a damage factor  $q$  which has a value of unity at the initial time and which decreases in value with time during the course of the mission such that the power output,  $p$ , of the arrays at any time may be written

$$p = q \gamma p_{\text{ref}}$$

where  $p_{\text{ref}}$  is the reference power and  $\gamma$  is the power factor which is a function of solar distance and array orientation relative to the sun. The damage factor  $q$  may also be thought of as a time-dependent efficiency. The derivative  $\dot{q}$  is negative, and is assumed to be linearly proportional to  $q$  and to the density of particles impinging on the solar cells. For simplicity, it is assumed that the particle density  $d$  is of the same form as the density of photons striking the surface of the array, i.e.,

$$d = \frac{\bar{\mathbf{e}}_r \cdot \bar{\mathbf{n}}}{r^2} \quad (1)$$

where  $\bar{e}_r$  is a unit vector along the sun-spacecraft line,  $\bar{n}$  is a unit vector normal to the arrays such that  $\bar{e}_r \cdot \bar{n} > 0$  implies the front of the panels faces the sun, and  $r$  is the solar distance of the spacecraft. In the discussion to follow, an upper case symbol will denote a vector, a lower case symbol will denote a scalar, and a lower case symbol with a bar will denote a unit vector. Then

$$\dot{q} = -kqd \quad (2)$$

and

$$q = e^{-k \int_0^t d dt'} \quad (3)$$

where  $k$  is the constant of proportionality. It is convenient to introduce a parameter  $s$ , called degradation time,

$$s = \int_0^t d dt' \quad (4)$$

or

$$\dot{s} = d \quad (5)$$

Thus, under the above assumptions the degradation time accumulates at a faster rate when the spacecraft is nearer the sun, which is a characteristic one might expect. Note that when the spacecraft is maintained at 1 AU with the panels normal to the sun line,  $\dot{s} = 1$  and the degradation time is equal to the flight time. Then  $k$  may conveniently be thought of as the inverse of a reference time, called the characteristic degradation time denoted by  $\tau_d$ , and the degradation factor  $q$  becomes

$$q = e^{-s/\tau_d} \quad (6)$$

Actually, there is little reason to allow the degradation time  $s$  to continue to accumulate during coast phases since the arrays may be turned edgewise to the sun and the degradation process may be effectively halted. Therefore, we adjust equation (5) to read

$$\dot{s} = h_{\sigma} d \quad (7)$$

where  $h_{\sigma}$  is a step function equal to one during thrust phases and equal to zero during coast phases.

The characteristic degradation time  $\tau_d$  is an engineering parameter that must be determined experimentally. For example, by exposing a solar cell to the particle emission of a solar simulator and measuring the performance of the cell over a period of time, one should be able to estimate a reasonable value of  $\tau_d$ . Another source of information would be measurements from actual spacecraft which employ solar cells for power supply.

The assumed exponential form of the degradation factor, although intended for use with SEP systems, is applicable for NEP systems as well. The principal difference is in the definition of  $\dot{s}$ ; for example,  $\dot{s} = h_{\sigma}$ . The exponential form also permits one to evaluate radio-isotope systems by defining  $\dot{s} = 1$  and letting  $\tau_d$  represent the time for the radioactivity to dissipate to  $1/e$  of its initial level.

In the development which follows, the formulation applicable to SEP is used exclusively. The equations of motion and adjoint equations are given in [1]; the equations affected by the inclusion of power degradation in the model are given below.

Power degradation affects the problem in a very fundamental sense, beginning with the rocket-thrust term in the equations of motion:

$$\begin{aligned}\dot{\mathbf{V}} = \ddot{\mathbf{R}} &= a \bar{\mathbf{e}}_t - \frac{\mu}{r^3} \mathbf{R} \\ \dot{\mathbf{R}} &= \mathbf{V}\end{aligned}\tag{8}$$

where  $\mathbf{R}$  is the position vector,  $r$  is the magnitude of  $\mathbf{R}$ ,  $\mathbf{V}$  is the velocity vector,  $\mu$  is the gravitational constant of the sun,  $a$  is the magnitude of the thrust acceleration and  $\bar{\mathbf{e}}_t$  is a unit vector in the direction of thrust. The thrust acceleration  $a$  is a function of several variables and may be written as follows:

$$a = h_{\sigma} \frac{g \gamma q}{\nu}$$

where  $g$  is a reference thrust acceleration evaluated under a prescribed set of conditions,  $\nu$  is the ratio of current to initial mass, and  $q$  is the degradation factor defined above. The power factor  $\gamma$  is assumed to be a function of the density,  $d$ , of photons incident on the arrays, where  $d$  is as written in equation (1). The general form of  $\gamma$  is

$$\gamma = d \sum_{i=0}^4 a_i d^{i/4} \quad (9)$$

The coefficients  $a_i$  are chosen so that this equation will adequately describe the power output of a given array. The only restriction on the  $a_i$  is that their sum is equal to one. Then at  $r = 1$  AU, with the arrays normal to the sun line,  $\gamma = d = 1$ . The summation term in (9) represents the temperature effect.

The mass ratio satisfies the differential equation

$$\dot{\nu} = - h_{\sigma} \frac{g \gamma q}{c}, \quad (10)$$

using  $\nu = 1$  as an initial condition, where  $c$  is the jet exhaust speed which is assumed to be constant over the trajectory.

The variational Hamiltonian becomes

$$\begin{aligned} h_v &= \Lambda \cdot \ddot{R} - \dot{\Lambda} \cdot \dot{R} + \lambda_{\nu} \dot{\nu} + \lambda_{\tau} \dot{\tau} + \lambda_s \dot{s} + \lambda_g \dot{g} + \lambda_c \dot{c} \\ &= h_{\sigma} \left[ \frac{g \gamma q}{\nu} (\Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_{\nu}) + \lambda_s d + \lambda_{\tau} \right] - \frac{\mu}{r^3} (\Lambda \cdot R) - \dot{\Lambda} \cdot \dot{R} \end{aligned} \quad (11)$$

and the adjoint equations are

$$\begin{aligned} \ddot{\Lambda} &= - \frac{\mu}{r^3} \Lambda + \frac{3\mu}{r^5} (R \cdot \Lambda) R + h_{\sigma} \left[ \frac{g \gamma^* q}{\nu} (\Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_{\nu}) + \lambda_s \right] \frac{\partial d}{\partial R} \\ \dot{\lambda}_{\nu} &= h_{\sigma} \frac{g \gamma q}{\nu^2} (\Lambda \cdot \bar{e}_t) \end{aligned} \quad (12)$$

$$\dot{\lambda}_g = -h_\sigma \frac{\gamma q}{\nu} (\Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu)$$

$$\dot{\lambda}_c = -h_\sigma \frac{g \gamma q}{c^2} \lambda_\nu$$

(12)  
(cont.)

$$\dot{\lambda}_s = h_\sigma \frac{g \gamma q}{\nu \tau_d} (\Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu)$$

where

$$\gamma^* = \partial \gamma / \partial d = \sum_{i=0}^4 a_i \left(1 + \frac{i}{4}\right) d^{i/4}$$

$$\frac{\partial d}{\partial R} = \frac{1}{r^3} \left[ \bar{n} - 3(\bar{e}_r \cdot \bar{n}) \bar{e}_r \right]$$

The control variables are the thrust direction  $\bar{e}_t$ , the switch step function  $h_\sigma$ , and, providing the array orientation is not constrained to yield maximum power, the normal direction  $\bar{n}$ . According to the Maximum Principle, these controls are chosen to maximize the variational Hamiltonian (11). The maximum of  $h_v$  with respect to  $h_\sigma$  is seen to depend totally on the sign of the term in square brackets. That is, denoting

$$\sigma = \frac{g \gamma q}{\nu} (\Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu) + \lambda_s d + \lambda_\tau \quad (13)$$

then choose

$$h_\sigma = \begin{cases} 1 & \text{if } \sigma > 0 \\ 0 & \text{if } \sigma < 0 \end{cases} \quad (14)$$

Maximizing  $h_v$  with respect to  $\bar{e}_t$  is also accomplished by inspection. Since  $\bar{e}_t$  appears only in the dot product with  $\Lambda$  and since the coefficient of that dot product is non-negative, i.e.,

$$h_\sigma g \gamma q / \nu \geq 0$$

then  $h_v$  is maximized with respect to  $\bar{e}_t$  by making  $\Lambda \cdot \bar{e}_t$  as large as possible,

which is the same result as when there is no degradation. The control vector  $\bar{n}$  appears explicitly in (11) through the density  $d$  as given by equation (1). In fact, since  $\bar{n}$  only appears in  $h_v$  through  $d$ ,  $\bar{n}$  only affects  $h_v$  through its dot product with  $\bar{e}_r$ . Letting the angle between  $\bar{n}$  and  $\bar{e}_r$  be denoted  $\chi$  such that  $\bar{e}_r \cdot \bar{n} = \cos \chi$ , then it is clear that there will be a "best" angle  $\chi$  between  $\bar{n}$  and  $\bar{e}_r$  to maximize  $h_v$ , but that  $\bar{n}$  may lie along any element of a right circular cone of half angle  $\chi$  about  $\bar{e}_r$ . For the moment, we will put aside the question of the explicit direction of  $\bar{n}$  and concentrate on defining the optimum  $\chi$  or, alternatively, the optimum  $d$ . The optimum value of  $d$  is determined by maximizing  $h_v$  with respect to  $d$ , i.e., by solving for the root of the equation

$$\frac{\partial h_v}{\partial d} = h_\sigma \frac{\partial \sigma}{\partial d} = 0 \quad (15)$$

Performing the indicated differentiation yields

$$\frac{g \gamma^* q}{\nu} \sigma_r + \lambda_s = 0 \quad (16)$$

or

$$\gamma^* = - \frac{\lambda_s \nu}{g q \sigma_r} \quad (17)$$

where, using (9),

$$\gamma^* = \sum_{i=0}^4 a_i \left(1 + \frac{i}{4}\right) d^{i/4} \quad (18)$$

and

$$\sigma_r = \Lambda \cdot \bar{e}_t - \frac{\nu}{c} \lambda_\nu$$

Because of the form of (18) equation (16) is a quartic in the variable  $d^{i/4}$ , and is solved by iteration in the program. A more detailed discussion of the solution to (16) is given in reference [3] for a specific set of coefficients  $a_i$ . For now, assume that the optimum value of  $d$  is found from (16). Then the optimum angle  $\chi$  is immediately obtained

$$\cos \chi = d r^2 \quad (19)$$

Of course, equation (16) does not take into consideration the fact that  $d$  can never exceed the inverse square of the solar distance. Consequently, the right hand side of (19) may exceed unity, under which condition the program sets  $\cos \chi \equiv 1$  (i.e.,  $\chi = 0$ ) implying that  $\bar{n}$  is directed along  $\bar{e}_r$ .

If the  $d$  that represents the solution to (16) exceeds the upper limit allowed for  $d$  whether that limit is imposed by the problem or by nature (i.e.,  $1/r^2$ ), the correct choice for  $d$  is that upper-limiting value. Likewise, on the lower side,  $d$  is physically limited to be non-negative. Therefore, a negative solution to (16) is disregarded, and  $d$  is set to zero which corresponds to  $\chi = \pi/2$  (panels oriented edgewise to the sun), and the engines are shut down.

The precise definition of  $\bar{n}$  has no bearing on the solution of the problem, except as it affects  $d$  as defined in (1). The appearance of  $\bar{n}$  in the state and adjoint equations and the variational Hamiltonian is solely through the density  $d$  except in the equation for  $\ddot{\Lambda}$  where  $\bar{n}$  appears explicitly as part of the partial  $\partial d / \partial R$ , defined following equations (12). Actually, this partial is valid only if  $d$  is permitted to vary with  $R$ . That is, if either  $d = 0$  or  $d = \text{constant}$  is imposed then  $\partial d / \partial R$  becomes the null vector and the entire term drops from the equation for  $\ddot{\Lambda}$ . Furthermore, if  $d$  is the solution to (16), then the last term of  $\ddot{\Lambda}$  in (12) again drops out because the term in square brackets is the left side of (16). Therefore, the only time the term in question remains in the equation for  $\ddot{\Lambda}$  is when  $d = 1/r^2$  which corresponds to  $\cos \chi = \bar{e}_r \cdot \bar{n} = 1$  and implies  $\bar{n} \equiv \bar{e}_r$ . Under this condition

$$\frac{\partial d}{\partial R} = - \frac{2}{r^3} \bar{e}_r.$$

The boundary condition pertaining to the initial degradation time is

$$s(t_0) = 0$$

Although transversality conditions are discussed in the next section, the transversality condition associated with degradation time is stated here for the sake of completeness. If the final degradation time,  $s_f$ , is unspecified,

$$\lambda_{s_f} = 0.$$

The initial value of  $\lambda_s$  is unknown and therefore becomes one of the independent parameters of the boundary value problem. From equations (12), it follows that

$$\dot{\lambda}_s = -\frac{g}{\tau_d} \lambda_g$$

and, therefore,

$$\lambda_{s_f} - \lambda_{s_o} = -\frac{g}{\tau_d} (\lambda_{g_f} - \lambda_{g_o})$$

Using the boundary conditions  $\lambda_{s_f} = \lambda_{g_o} = 0$ , it follows that

$$\lambda_{s_o} = \frac{g}{\tau_d} \lambda_{g_f}.$$

Thus, if an approximate value of  $\lambda_{g_f}$  is available from a trajectory similar to the one of interest, a reasonable guess of  $\lambda_{s_o}$  is readily available.

2. Housekeeping Power. This program option applies only to solar electric propulsion and is currently not integrated with the power degradation option. The program therefore does not allow the use of both options simultaneously. The new program input-quantity controlling the housekeeping power simulation is DPOW, which is the ratio of housekeeping power to reference power and is given the symbol  $\Delta p$ :

$$\Delta p = p_h / p_{ref}$$

The reference power  $p_{ref}$  is defined as the power input to the power conditioners\* under reference conditions. (For solar electric propulsion, reference conditions are equivalent to having the total spacecraft in a perfect solar-simulator such

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\*When the thrusters are at full-throttle.



that the simulated solar distance is one astronomical unit, the solar arrays are oriented normal to the source of energy, and no radiation damage or other degradation effects have occurred to any components).

This spacecraft model assumes that the powers required by the operating components at each instant of time exactly match the power developed by the solar arrays:

$$p_a = p + p_h$$

where  $p_a$  is the power developed by the arrays,  $p$  is the instantaneous power delivered to the power conditioners, and  $p_h$  is the housekeeping power, which is constant with time. Currently, all trajectories generated by the program using the housekeeping power simulation must satisfy the condition that  $p_a > p_h$ , so that  $p$  remains positive; in other words, engine shutdown when  $p \rightarrow 0$  is not coded into the program.

The power factor  $\gamma$  is defined as the ratio of instantaneous power to reference power,

$$\gamma = p/p_{\text{ref}} = (1 + \Delta p) \sum a_i d^{(i+4)/4} - \Delta p$$

where the summation quantity  $\Sigma$  is the power factor when  $p_h = 0$ .

The spacecraft model has been expanded by deleting the old, total propulsion system specific mass  $\alpha$  and replacing it with  $\alpha_a$ , the specific mass of the solar arrays, and  $\alpha_t$ , the specific mass of the thruster subsystem. The quantity previously called the "propulsion system mass" is now expressed,

$$m_{\text{ps}} = \alpha_a p_{\text{ao}} + \alpha_t p_{\text{ref}} = (\alpha_t + \alpha_a (1 + \Delta p)) p_{\text{ref}}$$

where  $p_{\text{ao}}$  is  $p_a$  evaluated under reference conditions (i.e.,  $p_{\text{ao}} = p_{\text{ref}} + p_h$ ), and the total specific mass  $\alpha$  has been replaced by  $(\alpha_t + \alpha_a (1 + \Delta p))$ , also a constant since the housekeeping power option is intended to be used only in

simulations where the reference power is specified. The remainder of the analysis describing the optimization problem remains unchanged.

## B. BOUNDARY AND TRANSVERSALITY CONDITIONS

The basic boundary conditions and transversality conditions are described in [1]; the nomenclature used in the following analysis is also described in [1], except for the introduction of new symbols which are described in the text as they appear.

In summary, when no intermediate-targets are present, individual transversality conditions are derived from the general equation

$$d\pi + [\Lambda \cdot dV - \dot{\Lambda} \cdot dR + \lambda_v d\nu + \lambda_s ds + \lambda_\tau d\tau + \lambda_g dg + \lambda_c dc - h_v dt]_0^n = 0$$

where  $\pi$  denotes the performance index which is assumed to be of the form

$$\pi = \pi(v_{\infty 0}, v_{\infty n}, \nu_n, g, c, t_o, t_f)$$

such that

$$d\pi = \pi_{v_{\infty 0}} dv_{\infty 0} + \pi_{v_{\infty n}} dv_{\infty n} + \pi_{\nu_n} d\nu_n + \pi_g dg + \pi_c dc + \pi_{t_o} dt_o + \pi_{t_n} dt_n$$

where  $\pi_x$  denotes  $\partial\pi/\partial x$ . The individual transversality conditions are obtained by equating to zero the coefficients of all independent differentials.

1. Deep Space Burn. In simulations of trajectories which are all-ballistic, the program is capable of simulating a single deep-space burn, or impulsive velocity-change, at any point prior to arrival at the primary target. The three components of the incremental velocity  $\Delta V$  are independent variables of the boundary value problem, such that, at a specified time, the spacecraft velocity is incremented:

$$\dot{R}^+ = \dot{R}^- + \Delta V$$

The use of this program option is described in the Sample Problems and Results section under sample Case C, Multiple Ballistic Swingby Mission.

2.  $V_{\infty}$  Optimization in LVI Mode. The optimization of the launch excess velocity  $V_{\infty}$  when using the Launch Vehicle Independent (LVI) mode of simulation is accomplished when the initial primer vector is forced to vanish:

$$\Lambda_0 = 0.$$

This is accomplished by setting the values of these three independent variables of the boundary value problem to zero and turning their triggers off; the three components of the departure heliocentric velocity become independent variables instead. The program contains special logic to circumvent the numerical singularity associated with the null primer vector.

3. Launch Asymptote Declination Optimization. This section contains the equations employed in the optimization of the launch asymptote declination. A more thorough exposition of this subject is found in [4], in which some of the ramifications of the theory are discussed. Historically, an incomplete form of this analysis was first published in the appendix of [1].

The assumed spacecraft and propulsion system models are as described in [1] and will not be repeated here. The launch vehicle payload capability is assumed to follow the simple exponential law

$$m_0 = b_1 e^{-(v_c/b_2)} - b_3, \quad (20)$$

where  $b_1$ ,  $b_2$ , and  $b_3$  are pre-determined constants for each launch vehicle and  $v_c$  is a characteristic speed representative of the energy required to achieve a specific escape trajectory.

The velocity penalty incurred with non-due-East launches from the ETR is shown graphically in Reference [5] as a function of the parking orbit inclination. This velocity penalty  $\Delta v_i$  is adequately approximated with a quadratic curve fit of the form

$$\Delta v_i = c_1 i^2 + c_2 i + c_3 \quad (21)$$

Given a reference orbit inclination  $i$  and a circular orbit speed  $v_o$ , the velocity penalty  $\Delta v_g$  associated with a non-coplanar departure from this circular orbit to the desired hyperbolic excess velocity at a declination  $\delta$  is defined as follows. Assuming the line of nodes of this reference orbit is an open variable, one may choose this variable to minimize the angle between the excess velocity and the orbital plane. This minimum angle is  $\delta - i$ . Gunther<sup>[6]</sup> has shown that the minimum incremental velocity required to achieve a given  $v_\infty$  along an asymptote not lying in the orbital plane from a specified circular orbit is obtained from the solution to a quartic equation in the sine of the out-of-plane angle. Defining

$$\begin{aligned} s &= \sin(\delta - i); \quad \rho = v_\infty / v_o; \\ p &= s^2 (\rho^2 + 4); \\ q &= s^2 (1 - s^2) \rho^2; \\ x &= \left[ \sqrt{(q/2)^2 + (p/3)^3} + q/2 \right]^{\frac{1}{3}} - \left[ \sqrt{(q/2)^2 + (p/3)^3} - q/2 \right]^{\frac{1}{3}}; \\ y &= \sqrt{\rho^2/4 - x}; \end{aligned} \quad (22)$$

$$w = \frac{1}{2} \left[ \rho/2 + y + \sqrt{(\rho/2 + y)^2 + 4 \left( x/2 + \sqrt{x^2/4 + s^2} \right)} \right],$$

then Gunther's solution for the magnitude of the minimum velocity impulse required to accomplish the maneuver is

$$v_g = v_o \sqrt{\rho^2 + 3 - 2 \sqrt{(1 + \rho w - w^2)(2 + \rho w)}}, \quad (23)$$

and the penalty  $\Delta v_g$  is the difference between  $v_g$  and the velocity increment required if the out-of-plane angle were zero, i.e.,

$$\Delta v_g = v_g - \left( \sqrt{v_\infty^2 + 2v_o^2} - v_o \right).$$

Thus, the definition of the characteristic speed for those cases in which the asymptote declination lies outside the interval  $[-i, i]$  is

$$\begin{aligned} v_c &= \sqrt{v_\infty^2 + 2v_0^2} + \Delta v_i + \Delta v_g \\ &= v_0 + v_g + \Delta v_i. \end{aligned} \quad (24)$$

The transversality conditions which optimize the launch phase are developed as follows. The state and adjoint equations for the problem under consideration are precisely as formulated in [1]. The only difference in the optimality conditions is the format and content of certain of the transversality conditions. Specifically, these differences are due solely to the new definition of  $v_c$  which is now a function of the direction of  $V_\infty$  as well as its magnitude. Whereas before the differential of  $v_c$  was, simply

$$dv_c = (v_\infty / v_c) dv_\infty,$$

it follows from (24) that the equivalent formula now is

$$\begin{aligned} dv_c &= (\partial v_g / \partial v_\infty) dv_\infty + (\partial v_g / \partial \delta) d\delta \\ &\quad + (\partial v_g / \partial i + \partial \Delta v_i / \partial i) di \end{aligned}$$

where, from (21)

$$\partial \Delta v_i / \partial i = 2c_1 i + c_2,$$

and, from (22) and (23),

$$\partial v_g / \partial i = - \partial v_g / \partial \delta.$$

The derivation of the partial derivatives  $\partial v_g / \partial v_\infty$  and  $\partial v_g / \partial \delta$  is straightforward although somewhat cumbersome. The equations for these partial

derivatives are as follows:

$$\frac{\partial v_g}{\partial v_\infty} = \frac{v_0^2}{v_g} \left\{ \rho \frac{\partial \rho}{\partial v_\infty} - \frac{w(3+2\rho w - w^2)(\partial \rho / \partial v_\infty) + (3\rho + 2\rho^2 w - 3\rho w^2 - 4w)(\partial w / \partial v_\infty)}{2\sqrt{(1+\rho w - w^2)(2+\rho w)}} \right\},$$

$$\frac{\partial v_g}{\partial \delta} = - \frac{v_0^2 (3\rho + 2\rho^2 w - 3\rho w^2 - 4w)}{2v_g \sqrt{(1+\rho w - w^2)(2+\rho w)}} \frac{\partial w}{\partial \delta},$$

where

$$\partial \rho / \partial v_\infty = 1/v_0,$$

$$\begin{aligned} \frac{\partial w}{\partial v_\infty} = \frac{1}{2} \left\{ \frac{1}{2} \frac{\partial \rho}{\partial v_\infty} + \frac{\partial y}{\partial v_\infty} + \left[ \left( 1 + \frac{x}{2\sqrt{x^2/4+s^2}} \right) \frac{\partial x}{\partial v_\infty} + \left( \frac{\rho}{2} + y \right) \left( \frac{1}{2} \frac{\partial \rho}{\partial v_\infty} \right. \right. \right. \\ \left. \left. \left. + \frac{\partial y}{\partial v_\infty} \right) \right] / (2w - \rho/2 - y) \right\}, \end{aligned}$$

$$\frac{\partial w}{\partial \delta} = \frac{1}{2} \left\{ \frac{\partial y}{\partial \delta} + \left[ \frac{\partial x}{\partial \delta} + \frac{x(\partial x / \partial \delta) + 4s(\partial s / \partial \delta)}{2\sqrt{x^2/4+s^2}} + \left( \frac{\rho}{2} + y \right) \frac{\partial y}{\partial \delta} \right] / (2w - \rho/2 - y) \right\},$$

$$\partial s / \partial \delta = \cos(\delta - i),$$

$$\partial y / \partial v_\infty = \left[ (\rho/2) \partial \rho / \partial v_\infty - \partial x / \partial v_\infty \right] / 2y,$$

$$\partial y / \partial \delta = - (\partial x / \partial \delta) / 2y,$$

$$\begin{aligned} \frac{\partial x}{\partial u} = \frac{1}{6} \left[ \frac{(q/2)(\partial q / \partial u) + (p/3)^2 (\partial p / \partial u)}{\sqrt{(q/2)^2 + (p/3)^3}} + \frac{\partial q}{\partial u} \right] \left[ \sqrt{(q/2)^2 + (p/3)^3} + q/2 \right]^{-2/3} \\ - \frac{1}{6} \left[ \frac{(q/2)(\partial q / \partial u) + (p/3)^2 (\partial p / \partial u)}{\sqrt{(q/2)^2 + (p/3)^3}} - \frac{\partial q}{\partial u} \right] \left[ \sqrt{(q/2)^2 + (p/3)^3} - q/2 \right]^{-2/3}, \end{aligned}$$

with  $u = v_{\infty}$  or  $\delta$ ,

$$\partial q / \partial v_{\infty} = 2\rho s^2 (1 - s^2) (\partial \rho / \partial v_{\infty}),$$

$$\partial q / \partial \delta = 2\rho^2 s (1 - 2s^2) (\partial s / \partial \delta),$$

$$\partial p / \partial v_{\infty} = 2\rho s^2 (\partial \rho / \partial v_{\infty}),$$

$$\partial p / \partial \delta = 2s(\rho^2 + 4) (\partial s / \partial \delta).$$

This concludes the computation of these two partial derivatives. Some symbols used in this section of the document apply to this section only; for example,  $p$  and  $q$  here are intermediate quantities in the analysis, and have no relation to power or degradation factor discussed elsewhere.

The differential of  $g$ , the reference thrust acceleration, is

$$dg = - (g/m_o) dm_o$$

where

$$dm_o = - (b_1/b_2) e^{-(v_c/b_2)} dv_c,$$

and the differential of  $V_{\infty}$  may be written

$$dV_{\infty} = (V_{\infty}/v_{\infty}) dv_{\infty} + (\bar{n}_p \times V_{\infty}) d\alpha + [(V_{\infty} \times \bar{n}_p) \times V_{\infty} / |V_{\infty} \times \bar{n}_p|] d\delta,$$

where  $\bar{n}_p$  is a unit vector along the North Pole and  $\alpha$  is the geocentric right ascension of  $V_{\infty}$ , and therefore the transversality conditions associated with  $V_{\infty}$  are as follows:

For optimum launch parking orbit inclination:

$$f(\partial \Delta v_i / \partial i - \partial v_g / \partial \delta) = 0. \quad (25)$$



For optimum launch excess speed:

$$f(\partial v_g / \partial v_\infty) - (\Lambda_o \cdot V_\infty) / v_\infty = 0. \quad (26)$$

For optimum launch asymptote declination:

$$f(\partial v_g / \partial \delta) - \Lambda_o \cdot [(V_\infty \times \bar{n}_p) \times V_\infty / |V_\infty \times \bar{n}_p|] = 0. \quad (27)$$

For optimum launch asymptote right ascension:

$$- \Lambda_o \cdot (\bar{n}_p \times V_\infty) = 0. \quad (28)$$

In the above equations  $f$  is given by

$$f = [k_s + k_t - (1 + k_t) \nu_f - g \lambda_g / m_o] dm_o / dv_c$$

Due to the complexity of the equations defining  $\partial v_g / \partial \delta$ , the solution of equation (25) for the optimum value of  $i$  must be obtained using an iterative technique.

The approach to the solution of the problem as formulated above differs in three basic respects from that of the problem where asymptote declination is ignored: (1) the condition (25) must be solved for the optimum parking orbit inclination, given values of  $v_\infty$  and  $\delta$ ; (2) the asymptote declination  $\delta$  must be introduced as an independent parameter and (27) added as an end condition of the problem; and (3) the evaluation of  $V_\infty$  becomes somewhat more involved. The computation of  $V_\infty$  given  $v_\infty$ ,  $\Lambda_o$  and  $\delta$ , proceeds as follows: Denote as  $\epsilon$  the obliquity of the ecliptic such that the matrix

$$\Phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \epsilon & -\sin \epsilon \\ 0 & \sin \epsilon & \cos \epsilon \end{bmatrix},$$

operating on a vector expressed in ecliptic Cartesian coordinates yields the same vector in Earth equatorial coordinates. Then the right ascension  $\alpha_\lambda$  of the initial primer  $\Lambda_o$  may be written

$$\alpha_\lambda = \tan^{-1} \left[ (\lambda_{yo} \cos \epsilon - \lambda_{zo} \sin \epsilon) / \lambda_{xo} \right],$$

where  $\lambda_{xo}$ ,  $\lambda_{yo}$ ,  $\lambda_{zo}$  are the given ecliptic coordinates of  $\Lambda_o$ . Then, the right ascension of the asymptote is set

$$\alpha = \alpha_\lambda \text{ or } \alpha = \alpha_\lambda + \pi,$$

and  $V_\infty$  is evaluated

$$V_\infty = v_\infty \Phi^T \begin{bmatrix} \cos \alpha \cos \delta \\ \sin \alpha \cos \delta \\ \sin \delta \end{bmatrix}.$$

4. Extra-Ecliptic Missions. An additional set of boundary conditions has been added to the program for simulating extra-ecliptic missions.

The original set of boundary conditions is given on pp. 25-26 of reference [1], which is now invoked by employing the program input quantity IOUT = 1 and corresponds to  $i$ ,  $e$ , and  $r_p$  specified,  $\Omega$  and  $\omega$  optimized and  $f = 0$ , where  $i$  is inclination to the ecliptic,  $e$  is eccentricity,  $r_p$  is perihelion distance,  $\Omega$  is ascending node angle,  $\omega$  is argument of perihelion, and  $f$  is true anomaly, all evaluated at the final time.

The new set of end conditions for extra-ecliptic missions is invoked by IOUT = 2 and is similar to the original set except that the final true anomaly is optimized rather than specified as zero, which corresponds to having the spacecraft arrive at the optimum point of the extra-ecliptic orbit rather than being constrained to arrive at perihelion. The specified final conditions are  $i$ ,  $e$ , and  $a$ , where  $a$  is the final semi-major axis (in place of  $r_p$ ).  $\Omega$  and  $\omega$  are optimized

as before, using the transversality conditions

$$T(\Omega) = \bar{k} \cdot C = 0 \quad (29)$$

$$T(\omega) = \bar{h} \cdot C = 0 \quad (30)$$

which are identical to equations (47) and (48) of reference [1].  $C = R \times \dot{\Lambda} - \dot{R} \times \Lambda$  is the vector constant of the motion on a given trajectory segment,  $\bar{h}$  is a unit vector along the angular momentum of the final orbit, and  $\bar{k}$  is the z-axis unit vector. Optimizing  $f$  is accomplished by satisfying the transversality condition associated with  $f$ :

$$T(f) = \frac{\mu}{r} (\Lambda \cdot R) + r^2 (\dot{\Lambda} \cdot \dot{R}) = 0 \quad (31)$$

The program attempts to satisfy equations (29), (30), and (31) directly, since no closed-form solution has yet been found for casting these end conditions in the form of  $\Delta R$  and  $\Delta \dot{R}$  similar to equations (54) and (55) of reference [1]. These end conditions possess poor convergence properties, a fact which the authors have experienced directly in attempting to obtain converged solutions using IOUT = 2.

5. Multiple Target Missions - Errata. Two equations in the section, Extension of Formulation for Multiple-Target Missions of reference [1] are in error. Equation (116) of reference [1] should read

$$\begin{aligned} \pi = & j_r m_{rs} + m_o \left\{ k_s + k_t - (1 + k_t) \nu_n + j_r (1 + k_{rt}) e_x \left[ (1 + j_t k_t) \nu_n \right. \right. \\ & \left. \left. - j_t k_t \left( 1 + \sum_{i=1}^{n-1} (k_{sami} - k_{dropi}) \right) \right] + (1 + k_t) \sum_{i=1}^{n-1} k_{sami} \right. \\ & \left. - k_t \sum_{i=1}^{n-1} k_{dropi} \right\} + m_{ps} \left[ 1 - j_r j_{ps} (1 + k_{rt}) e_x \right] \end{aligned}$$

and equation (117) should read

$$\begin{aligned} \pi_{m_o} = \frac{\partial \pi}{\partial m_o} = & k_s + k_t + j_p \frac{\alpha_{gc}}{2\eta} - (1+k_t) \nu_n + (1+k_t) \sum_{i=1}^{n-1} k_{sampi} \\ & - k_t \sum_{i=1}^{n-1} k_{dropi} + g_x \left[ (1+j_t k_t) \nu_n - j_t k_t \left( 1 + \sum_{i=1}^{n-1} (k_{sampi} - k_{dropi}) \right) \right. \\ & \left. - j_p j_{ps} \frac{\alpha_{gc}}{2\eta} \right]. \end{aligned}$$

### C. AUXILIARY COMPUTATIONS

This section presents equations employed in computations which are made after the iteration sequence involving the primary target is completed.

1. Additional Block Print Variables. A standard print block is employed for printing information at various points along a trajectory. Each standard block contains a total of forty parameters, which are described in [1].

The standard block may be augmented in two ways. When power degradation, as indicated by the input variable TPOWER, is simulated, a single line of information is automatically added to each block, as displayed in the Sample Problems and Results section, Case B, Comet Rendezvous Mission. When the input variable MPRINT is 2 or 3, three extra lines of information are generated per block, as displayed in the Sample Problems and Results section, Case C, Multiple Ballistic Swingby Mission. These two types of additionally printed lines may appear simultaneously.

(a). Power Degradation. The single line of power degradation information contains eight parameters as follows:

S	Degradation time, $s$ , since departure, in days, given by expression (4).
LS	Degradation time adjoint variable, $\lambda_s$ .
DENSITY	Density parameter, $d$ , used in expression (9) for the power ratio $\gamma$ , and given by expression (1), in $AU^{-2}$ .
DPOWR	$\partial\gamma/\partial r$ , in $AU^{-1}$ .
DPOWD	$\partial\gamma/\partial d$ .
DEGRAD	The degradation factor, $q$ , given by expression (6).
CHI	Solar array orientation angle $\chi$ as given by, for example, expression (19), in degrees.

CHI REF

Solar array orientation angle which the arrays would have if oriented for maximum power, in degrees.

(b). Target-Relative Coordinates and Comet Magnitudes. The three extra lines which may appear via using MPRINT contain the following information:

R1 REL

R2 REL

R3 REL

Cartesian components of current spacecraft position vector, with respect to the next astronomical body to be encountered along the trajectory in a moving coordinate system generated by that body, with the x-axis pointing outward along the body's heliocentric radius vector, the y-axis in the body's orbit plane in the direction of the body's motion, and the z-axis completing the right-handed orthogonal system, in kilometers, with the origin of coordinates at the body.

V1 REL

V2 REL

V3 REL

Cartesian components of current spacecraft velocity vector, in kilometers/second, in the target-relative coordinate system described directly above (see R1 REL).

RMAG REL

Magnitude of R1 REL, R2 REL, R3 REL, in kilometers.

VMAG REL

Magnitude of V1 REL, V2 REL, V3 REL, in kilometers/second.

S/C NUC MAG

Nuclear magnitude (of comet) of the next astronomical body to be encountered along the trajectory, as seen by the spacecraft.

$$M_N = M_O + M_1 \log_{10} |R - R_{\text{targ}}| + M_2 \log_{10} |R_{\text{targ}}| \\ + .03 \cos^{-1} \left[ \frac{R_{\text{targ}} \cdot (R_{\text{targ}} - R)}{|R_{\text{targ}}| |R_{\text{targ}} - R|} \right] C^0$$

where  $M_O$ ,  $M_1$ , and  $M_2$  are magnitude constants

(Continued on next page)

S/C NUC MAG  
(continued)

associated with the target, and  $C^0$  is the radians-to-degrees conversion factor. The arc-cosine term is the phase angle.

S/C TOT MAG

Total magnitude of the next astronomical body to be encountered along the trajectory, as seen by the spacecraft.

$$M_T = M_3 + M_4 \log_{10} |R - R_{\text{targ}}| + M_5 \log_{10} |R_{\text{targ}}|$$

where  $M_3$ ,  $M_4$ , and  $M_5$  are magnitude constants associated with the target.

GEO NUC MAG

Same as S/C NUC MAG, except as seen by the Earth.

GEO TOT MAG

Same as S/C TOT MAG, except as seen by the Earth.

ANG(V, R)

Angle which (V1 REL, V2 REL, V3 REL) makes with the positive x-axis in the target-relative coordinate system described under R1 REL, in degrees.

$$\text{ANG}(V, R) = \cos^{-1} (V1 \text{ REL} / VMAG \text{ REL})$$

ANG(V, XY)

Angle which (V1 REL, V2 REL, V3 REL) makes with the xy plane in the target-relative coordinate system described under R1 REL, in degrees.

$$\text{ANG}(V, XY) = \sin^{-1} (V3 \text{ REL} / VMAG \text{ REL})$$

R1 REL ECL  
R2 REL ECL  
R3 REL ECL

Same as R1 REL, R2 REL, R3 REL except expressed in the ecliptic coordinate system of date.

V1 REL ECL  
V2 REL ECL  
V3 REL ECL

Same as V1 REL, V2 REL, V3 REL except expressed in the ecliptic coordinate system of date.

RMAG ECL

Magnitude of R1 REL ECL, R2 REL ECL, R3 REL ECL, in kilometers.

VMAG ECL

Magnitude of V1 REL ECL, V2 REL ECL, V3 REL ECL, in kilometers/second.

2. Swingby Continuation Analysis. Auxiliary computations are optionally provided, invoked by the NAMELIST input vector MOPT4, whereby ballistic swingbys past the primary target may be simulated.

In one mode of program operation, invoked by  $\text{MOPT4}(1) > 0$ , single swingbys past the primary target may be simulated to up to ten post-swingby targets per case.

In another mode of program operation, invoked by  $\text{MOPT4}(1) < 0$ , multiple swingbys along a single trajectory may be simulated, first swinging past the primary target and then subsequently swinging past more targets downstream along the trajectory. One multiple swingby trajectory may be simulated per case.

In either mode of operation, the following basic assumptions are made. The swingby continuation computations are independent of the trajectory leg leading up to the swingby target, which may consist of an optimized electric propulsion trajectory segment (if the swingby target is the primary target), except that the arrival  $V_\infty$  and arrival time at the swingby target are used in the determination of the swingby passage conditions. Each swingby maneuver is calculated under the assumption of the patched-conic approximation, and the swingby planet's sphere-of-influence is assumed to have zero radius as seen from interplanetary space and infinite radius as seen from the planetary vantage point. The passage time in the swingby planet's sphere-of-influence is neglected (taken to be zero in the heliocentric frame).

Each swingby maneuver may be either unpowered or powered, and these two cases are discussed in the following sections. Since the unpowered swingby solutions are embedded in the wider class of powered-swingby solutions, tending to appear in pairs which are separated by a region of braking powered swingbys, the more general case of powered swingbys is discussed first.



(a). Powered Swingbys. This type of swingby maneuver is restricted to occur at the mutual perifoci of the approach and departure hyperbolic arcs; the powered phase is impulsive and the thrust is colinear (pro or con) to the velocity at closest approach. Whether the swingby is powered or unpowered, the trajectory segment leading up to the swingby planet has been pre-determined, this being the method by which the program has been designed to obtain swingby solutions. Therefore the swingby time and the arrival hyperbolic excess velocity  $V_{\infty A}$  are known. In the following analysis, subscript A pertains to arrival at the swingby planet and subscript D pertains to departure.

A basic assumption of the powered swingby problem posed here is that the flight time from the swingby planet to the next target is specified. This being so, the program is able to converge, by iteration, on some ballistic trajectory from the swingby planet to the next target having the specified transfer time, implying that the departure hyperbolic excess velocity  $V_{\infty D}$  at the swingby planet is thereby determined. Therefore, the heliocentric trajectory before and after the swingby planet is determined, and it then remains to perform the required computations pertaining to the hyperbolic arcs within the swingby planet's sphere of influence.

The closest approach distance is found by iteration as follows. Let

$$\alpha_A = 1 + \frac{r_p v_{\infty A}^2}{\mu}$$

and

$$\alpha_D = 1 + \frac{r_p v_{\infty D}^2}{\mu}$$

where  $v_{\infty A} = |V_{\infty A}|$ ,  $v_{\infty D} = |V_{\infty D}|$ ,  $r_p$  is the (unknown) passage distance, and  $\mu$  is the swingby planet's gravitational parameter. Then the approach and departure hyperbolic bend angles are given by

$$\frac{\delta_A}{2} = \operatorname{cosec}^{-1} \alpha_A = \sin^{-1} (1/\alpha_A)$$

$$\frac{\delta_D}{2} = \operatorname{cosec}^{-1} \alpha_D = \sin^{-1} (1/\alpha_D)$$

and these must sum up to the total bend angle, which is specified in terms of  $V_{\infty A}$  and  $V_{\infty D}$ :

$$\delta_T = \frac{\delta_A}{2} + \frac{\delta_D}{2} = \cos^{-1} \left[ \frac{V_{\infty A} \cdot V_{\infty D}}{V_{\infty A} V_{\infty D}} \right]$$

Therefore, using  $r_p$  as the independent variable, the zero of the quantity

$$F = \sin^{-1} (1/\alpha_A) + \sin^{-1} (1/\alpha_D) - \cos^{-1} \left[ \frac{V_{\infty A} \cdot V_{\infty D}}{V_{\infty A} V_{\infty D}} \right]$$

is obtained by Newton's iteration, using the derivative

$$\frac{\partial F}{\partial r_p} = \left( \frac{-1}{\mu} \right) \left[ \frac{v_{\infty A}^2 / \alpha_A}{\sqrt{\alpha_A^2 - 1}} + \frac{v_{\infty D}^2 / \alpha_D}{\sqrt{\alpha_D^2 - 1}} \right]$$

When the iteration is converged, the passage distance  $r_p$  is in hand, and the impulsive velocity increment is computed,

$$\Delta v = \sqrt{\frac{2\mu}{r_p} + v_{\infty D}^2} - \sqrt{\frac{2\mu}{r_p} + v_{\infty A}^2}$$

where the square-root-quantities are the hyperbolic speeds at closest approach.

The remaining parameters defining the planetocentric transfer are computed as follows. The inclination of the swingby orbit plane to the planet's equator is given by

$$i = \cos^{-1} (\bar{h} \cdot \bar{n}_p)$$

where  $\bar{h}$  is the unit vector along the angular momentum of the hyperbolic passage trajectory and  $\bar{n}_p$  is a unit vector pointing toward the swingby planet's north pole.

The ascending node angle of the swingby orbit plane is computed as

$$\Omega = \tan^{-1} (-h_x/h_y)$$

and is placed in the proper quadrant by using the system library routine DATAN2.

The argument of perifocus is given by

$$\omega = \cos^{-1} (\hat{r}_p \cdot \hat{r}_n)$$

where  $\hat{r}_p$  is the unit vector pointing toward the closest approach point and  $\hat{r}_n$  is the unit vector lying along the line of nodes and pointing toward the ascending node. This is adjusted for the proper quadrant by the test,

$$\text{If } h_z (\hat{r}_n \times \hat{r}_p)_z < 0, \quad \omega \rightarrow 2\pi - \omega$$

In the right-handed planetary reference frame, the  $z$ -axis is toward the planet's north and the  $x$ -axis points toward the ascending node of the planet's equator on the ecliptic plane.

(b). Unpowered Swingbys. This type of swingby maneuver is considered to be a powered swingby having  $\Delta v = 0$ . The program adjusts the post-swingby heliocentric trajectory segment, by iteration, until the swingby departure  $V_\infty$  magnitude equals the given arrival  $V_\infty$  magnitude. The primary independent variable in this iteration is the post-swingby transfer time to the specified target, which was held constant in the powered swingby case. Thus  $v_{\infty D} = v_{\infty A} = v_\infty$ , and the swingby passage distance is obtained from the formula,

$$r_p = \frac{\mu}{v_\infty^2} \left( \frac{2v_\infty}{|V_{\infty A} - V_{\infty D}|} - 1 \right)$$

The other orbital parameters are obtained from the same relations given above in the section, Powered Swingbys.

The program can generate multiple-revolution ballistic arcs, and a particular solution obtained by the program may not be unique, even for the same transfer time. All solutions are reachable, however, by means of inputting an appropriate initial velocity guess for the trajectory segment in question.

### III. PROGRAM INPUT

The following consists of a complete description of program inputs. With respect to the basic HILTOP report [1], several input quantities have been added, some have been deleted, and some definitions have been modified. The input quantities which have been deleted are CALPHA, DIGIT, HALT, and WEIGHT, and so these names must no longer appear in NAMELIST MINPUT input data sets. CALPHA has been replaced by ALPHAA and ALPHAT. Also,  $Y_i(4)$  and  $Y_i(5)$  for  $i = 1, 2, 3, \dots, 70$  have been deleted (See the description of "dependent parameters" in the section just ahead, Definitions of Input Parameters) and should therefore also be removed from input data sets.

## A. NAMELIST

Inputs to HILTOP are given through the NAMELIST feature of the IBM Fortran IV programming language. The input NAMELIST is named MINPUT, and every input required or used in the program is declared by name in the list. The general form for assigning an input value to a quantity is, simply,

$$\text{NAME} = \text{VALUE}$$

where NAME is the name assigned to the variable and is included in the NAMELIST, and VALUE is a numerical or logical quantity consistent in form (i.e., logical, integer, or real) with NAME. Unless otherwise specified, all MINPUT names commencing with one of the letters I through N represent integers, whereas all names commencing with one of the letters A through H or O through Z are double precision floating point numbers. Each NAMELIST case must begin with the characters

$$\&\text{MINPUT}$$

commencing in card column 2 and followed by at least one blank, and end with the characters

$$\&\text{END}$$

preceded by at least one blank. Card column 1 is ignored on all NAMELIST input cards. Multiple data assignments on a single card are permissible if separated by commas. Blanks in the variable field, VALUE, are taken as zeroes. A comma following the last VALUE on a card is optional on the IBM system. The order of the input data assignments is arbitrary; i.e., they need not be in the same order as listed in the NAMELIST. In fact, there is no requirement that any specific input parameter be represented in the input data set. If no value is included in the inputs for a particular parameter, the default value is used (see Default Values). For other details regarding the NAMELIST feature, the reader is referred to the IBM System 360/Fortran IV

Language manual. NAMELIST cases may be stacked back-to-back indefinitely.  
A single NAMELIST error may wipe-out the remaining NAMELIST inputs.

## B. DEFINITIONS OF INPUT PARAMETERS

Specific examples of the program inputs are given in the Sample Problems and Results section. Default-values of inputs are given in the next section.

The program inputs, in alphabetical order, are:

AAI	Desired final extra-ecliptic inclination. Related to AE, AR, and IOU. [deg]
AE	Desired final extra-ecliptic eccentricity. Related to AAI, AR, and IOU.
ALPHAA	Specific mass of solar arrays, $\alpha_a$ . [kg/kw]
ALPHAT	Specific mass of thruster subsystem, $\alpha_t$ . [kg/kw]
ALTTU	This input variable is associated with program logic which has not been kept up-to-date, specifically, logic pertaining to optimum departure of a NERVA-type rocket from Earth orbit. This variable should be ignored.
AN	Trajectory-integration exponent in expression (37) of reference [1].
AR	Desired final extra-ecliptic perihelion distance. Related to AAI, AE, and IOU. [AU]
ASOL	Array of five elements consisting of the solar power law coefficients $a_i$ in expression (17) of reference [1]. ASOL(1) > 0 tells the program to use the input coefficients rather than the internal coefficients. The coefficients are normalized internally, and the program executes the iterations to produce the required remarkable points of the power curve (which are printed).
BI	Efficiency coefficient $b$ in expression (15) of reference [1]. Related to DI and EI.
B1 B2 B3	Launch vehicle coefficients $b_1$ , $b_2$ , and $b_3$ in expression (2) of reference [1]. Used only if MBOOST is negative. [kg, m/sec, kg]



CNI	Inclination to ecliptic of primary-target orbit. Input only when MOPT3 = 11. Related to ECI, OMI, SAI, SOI, TPI, EMUODD, and RADODD. [deg]
CNIX	Array of five elements, the first three of which may be currently used. Inclinations to ecliptic of intermediate-target orbits. Input CNIX(i) only when MOPTX(i) = 11. Related to ECIX, OMIX, SAIX, SOIX, TPIX, EMUODX, and RADODX. [deg]
CSTR	Structural factor, $k_s$ , in expression (7) of reference [1].
CTANK	Propellant tankage factor, $k_t$ , in expression (6) of reference [1].
CTRET	Retro tankage factor, $k_{rt}$ , in expression (10) of reference [1].
DI	Efficiency coefficient $d$ in expression (15) of reference [1]. Related to BI and EI. [km/sec]
DMRETR	Retro engine mass, $m_{rs}$ , in expression (10) of reference [1]. [kg]
DPOW	Ratio of housekeeping power $p_h$ to reference power $p_{ref}$ . The power transmitted to the propulsion system is that generated by the arrays less housekeeping power which is constant along the trajectory. The power output of the arrays normal to the sun at 1 AU is $p_{ref} + p_h$ .
ECI	Eccentricity of primary-target orbit. Must be less than unity. Input only when MOPT3 = 11. Related to CNI, OMI, SAI, SOI, TPI, EMUODD, and RADODD.
ECIX	Array of five elements, the first three of which may be currently used. Eccentricities of intermediate-target orbits. Input ECIX(i) only when MOPTX(i) = 11. Related to CNIX, OMIX, SAIX, SOIX, TPIX, EMUODX, and RADODX.
EI	Efficiency coefficient $e$ in expression (15) of reference [1]. Related to BI and DI.

EMUODD	Gravitational constant of primary-target. Input only when MOPT3 = 11. Related to ECI, CNI, OMI, SAI, SOI, TPI, and RADODD. [ $\text{m}^3/\text{sec}^2$ ]
EMUODX	Array of five elements pertaining to the gravitational constants of intermediate-targets. These inputs must be ignored at present.
GAMMAX	Maximum permissible value of the power function $\gamma$ when MODE = 5. At solar distances less than the value for which $\gamma = \text{GAMMAX}$ , the solar arrays are assumed to be tilted such that $\gamma$ is maintained at the limiting value.
GAP	Propulsion-corner proximity tolerance-interval, $\Delta\sigma$ . See the discussion in the section Avoiding Corners in the Propulsion-time Function in reference [1]. Whenever the thrust switch function $\sigma$ grazes the zero-axis within the tolerance $ \Delta\sigma $ on any trajectory, an internal counter is incremented, and the trajectory is considered to be in the neighborhood of a propulsion-time corner. Positive value of GAP causes forced-thrusting case to be inserted, negative value causes bypass to next case, whenever the internal counter reaches the related input variable NHUNG.
HOURL	Hour-of-day of reference date (e.g., 17.342D0). Related to MYEAR, MONTH, and MDAY.
IBAL	Ballistic option indicator. Setting IBAL $\neq 0$ invokes option 1 discussed in the section Ballistic Trajectory Option of reference [1].
INTPR	Indicator which specifies print-length when the iteration in subroutine INTERP fails. Value of 0 causes short-print and 1 causes detailed-print.
IOUT	Extra-ecliptic mission indicator. IOUT = 1 or 2 indicates that extra-ecliptic target conditions are desired, in which the iterator dependent variable triggers Y1(2) through Y6(2) are set equal to 1, and for which the input LAUNCH (which see) should probably be set to 1, and parameters related to LAUNCH also set appropriately. Ordinarily MOPT2 = 3. No retro stage may be employed. (Continued on next page).

IOUT	= 1	i, e, $r_p$ specified; $f = 0$ .
(cont)	= 2	i, e, a specified; $f$ optimized.

In the above,  $i$  = final extra-ecliptic inclination,  $e$  = final eccentricity,  $r_p$  = final perihelion distance,  $a$  = final semi-major axis, and  $f$  = true anomaly at the final time. Final  $\Omega$  and  $\omega$  are optimized in both cases. Related to AE, AR, and AAI.

IRK Numerical integration option (currently not used).

IRL Primer-origin-proximity step-size-control indicator. Value of zero causes bypass of control, leaving the step-size  $\Delta u$  constant. See discussion in the section, Integration (Thrust) of reference [1].

IROT A non-zero value of IROT causes the input ecliptic projection of the primer vector and its time derivative to be rotated about the z-axis through an angle equal to the difference in longitudes of the spacecraft between the last trajectory of the previous case (or zero if no previous case) and the first trajectory of the current case. This feature permits one to use the initial adjoint variables from a 2-dimensional trajectory as the initial-guess inputs for a 3-dimensional trajectory using the ephemeris option. IROT must be set back to zero to avoid undesirable rotations on subsequent cases.

ISPIN Spinner indicator. Not used at present.

ITF Provides normal termination conditions for runs which require more machine time than is estimated. The value specifies the number of machine-time seconds (CPU and I/O) required to execute the summary trajectory after halting the iteration-sequence. [sec] Does not apply if subroutine REMTIM is dummied.

ITPRNT Indicator for special print from MINMX3 iterator. Non-zero value invokes print.

JPP Jettison indicator  $j_{ps}$  for electric propulsion system prior to primary-target retro-maneuver, as used in expression (8) of reference [1]. (Continued on next page).

JPP  
(cont)                      = 0 Propulsion system not jettisoned  
                              = 1 Propulsion system jettisoned prior to retro maneuver.

JPRINT                      Unit 11 printout-length indicator. A value of zero causes the iterator independent and dependent variables to be output only for each summary-trajectory; a value of one causes the same output additionally at each iteration of an iteration-sequence.

JT                            Jettison indicator  $j_t$  for electric propulsion tankage prior to primary-target retro-maneuver, as used in expression (8) of reference [1].

                              = 0 Tankage not jettisoned  
                              = 1 Tankage jettisoned prior to retro-maneuver.

KPART                        Option for automatically selecting improved independent parameter perturbations for generating the iterator's partial derivative matrix. The option is invoked by setting  $KPART = N$  ( $N > 0$ ), where  $N$  is the maximum number of allowed steps, as discussed in the section, Perturbation Step Size Selector of reference [1].  $KPART$  must be set back to zero if not desired on subsequent cases.

LAUNCH                        Launch mode selector, pertaining to the optimization of the departure asymptote declination, invoked by  $LAUNCH = 1$ . Related to  $X10$ ,  $Y10$ ,  $X17$ , and  $Y17$ .

LOADX                        Intermediate-target initial-guess feature. Should be used with  $NSET(5) = 1$ , and then set to zero on the subsequent case. A non-zero value of  $LOADX$  will invoke this feature, whereby the primer  $\Lambda$  and its derivative  $\dot{\Lambda}$  will be loaded into the iterator independent-variable arrays at each intermediate-target (Continued on next page).

LOADX (cont) provided that the trigger of the independent variable is on. The sole purpose of this capability is merely to generate an initial-guess for a multiple-target mission, where the values loaded into the iterator arrays represent continuous  $\dot{A}$  and  $\ddot{A}$  at each target.

MAXHAM Maximum number of times that the program will print the warning message BAD HAMILTONIAN on any given computer run.

MBOOST Launch vehicle selector.

= 0	ATLAS (SLV3X)/CENTAUR
1	TITAN III C
2	TITAN III C (1207)
3	TITAN III X/CENTAUR
4	TITAN III X (1207)
5	TITAN III X (1207)/CENTAUR
6	SATURN IB/LM
7	SATURN IB/CENTAUR
8	SATURN IC/SIVB/CENTAUR
9	TITAN III X (1205)/CENTAUR
10	TITAN III B (CORE)/CENTAUR
11	TITAN III D (1205)/CENTAUR
12	DELTA
13	TITAN III D
14	TITAN III D (1205)/CENTAUR/TE364 (2250)
15	TITAN III E/CENTAUR
16	SHUTTLE/TRANSTAGE
17	SHUTTLE/DELTA
18	SHUTTLE/AGENA
19	SHUTTLE/CENTAUR
20	SHUTTLE/CENTAUR/BURNER II (2300)
NEG	Use input booster coefficients $b_1$ , $b_2$ , and $b_3$ .

MDAY Day-of-month of reference date (e.g., 26). Related to MYEAR, MONTH and HOUR.

MODE Power variation option selector. The value of MODE is equal to the option-number of the power-curve, discussed in the section, Electric Propulsion System of reference [1] (which see). Possibly related to ASOL and GAMMAX. MODE = 1 has been eliminated.

MONTH Month-of-year of reference date (e.g., 8). Related to MYEAR, MDAY, and HOUR.

MOPT Ballistic option indicator. Using MOPT invokes option 2, discussed in the section, Ballistic Trajectory Option, of reference [1], as follows:

- = 0 No action (use input  $\Lambda_o$ ,  $\dot{\Lambda}_o$ , and  $v_{\infty o}$ ).
- = 1 Generate ballistic solution with flyby end conditions.
- = 2 Generate ballistic solution with orbiter end conditions.

Related to REVS.

MOPTX Array of five elements, the first three of which may be currently used. This array specifies the target-number, or planet-number, of the successive intermediate-targets, and a value of zero indicates absence of the intermediate-target. A zero-entry must not precede a non-zero entry. Planet selection is the same as for MOPT2. MOPTX(1) pertains to iterator parameters X41-X50 and Y41-Y50; MOPTX(2) pertains to X51-X60 and Y51-Y60; and MOPTX(3) pertains to X61-X70 and Y61-Y70. Times at the targets are X48, X58, and X68. Not to be used unless MOPT2  $\neq$  0.

MOPT2 Launch planet number and ephemeris-option indicator.

- = 0 Analytical planetary ephemeris is not used.
- $\neq$  0 Analytical planetary ephemeris is used and the specific launch planet is selected as follows: (Continued on next page).

= 1 Mercury	= 14 Icarus (1978)*
2 Venus	15 Eros
3 Earth	16 Geographos (1983)*
4 Mars	17 Encke (1977)*
5 Jupiter	18 Encke (1984)*
6 Saturn	19 Encke (1987)*
7 Uranus	20 Halley
8 Neptune	21 Betulia
9 Pluto	22 Toro (1983)*
10 Ceres	23 Pallas
11 Input Target**	24 Juno
12 D'Arrest (1982)*	25 Vesta
13 Encke (1980)*	26 Astraea

\*Year-value indicates apparition for which internal orbital elements are most accurate.

\*\*Input corresponding orbital elements (see CNI, CNIX). None are available for the launch planet.

MOPT2	= 27 Hebe
(cont)	28 Iris
	29 Flora
	30 Achilles
	31 Amor
	32 Hidalgo
	33 Alinda
	34 Grigg-Skjellerup (1977)*
	35 Kopff
	36 Grigg-Skjellerup (1982)*
	37 Ganymed
	38 Ivar
	39 Beira
	40 Kepler
	41 Giacobini-Zinner (1985)*
	42 Borrelly (1987)*
	43 Tempel II (1988)*
	44 Tempel II (1983)*
	45 Tuttle-Giacobini-Kresak
	46 Schaumasse
	47 Honda-Mrkos-Pajdusakova
	48 Giacobini-Zinner (1979)*
	49 Icarus (1987)*
	50 Toro (1987)*
	51 Geographos (1987)*

\*Year-value indicates apparition for which internal orbital elements are most accurate.

MOPT3      Planet number of primary-target. Planet selection is the same as for MOPT2. If ephemeris is not used, MOPT3 is used only for retro-stage mass computations.

MOPT4      Array of ten elements, specifying up to ten post-swingby targets. Planet selection is the same as for MOPT2, and a value of zero indicates the absence of a post-swingby target. A negative value in MOPT4(1) selects multiple ballistic swingbys, rather than a set of single swingbys in which case also set MAXHAM = 0. Negative values (in absolute value) produce planet selection the same as for MOPT2. When MOPT4(1) < 0, the remaining elements of MOPT4(i) may be positive or negative. See the section, Swingby Continuation Analysis for details and Sample Case C for an example-case. Should be used only for primary-target flyby missions. Related to T2, MSWING, NSWING and XSWING.

**MPOW** Flag used in conjunction with the solar array degradation option. Value of zero results in the optimum orientation of the arrays relative to the sun line. A non-zero value forces the arrays to an orientation yielding the maximum power achievable at that instant. Related to TPOWER.

**MPRINT** Indicator for printing the summary-trajectory (final trajectory of a case) as a function of time or for invoking extra printout.

- = 0 Small-size block print at thrust switch points only (SWITCH POINT SUMMARY page).
- = 1 Same as = 0, except expands to become a standard print-block of parameters for each computed point along the trajectory, including the trajectory extension controlled by the input variable TGO.
- = 2 Same as = 0, except each block contains extra lines consisting of target-relative coordinates and target magnitudes.
- = 3 Combination of =1 and =2.

**MPUNCH** Punched-card and trajectory-tape generation control.

- = 0 No special output.
- 1 Punch final values of independent parameters.
- 2 In addition, punch selected mission analysis parameters used for graphic documentation or other purposes.

< 0 and > -100 Punch trajectory output used with the ASTEA program. The absolute value of MPUNCH determines the frequency of trajectory points output.

≤ -101 Trajectory tape output used with the ASTEA program. The absolute value less 100 determines the frequency of trajectory points output. Related to NTAPE.



## MRREAD

Card input option (iterator independent variables)

= 0 No special cards input.

- 1 The independent variables generated by a previous run by the MPUNCH option are input following the NAMELIST case, as discussed in the section, Program Output, of reference [1].

## MSWING

Array of ten elements, used only when running multiple-target ballistic swingbys, such that MSWING(i) corresponds to MOPT4(i) and selects the type of swingby maneuver desired at the respective swingby target. Used only if MOPT4(i) < 0. The shooting method (MINMX3 iterator) is used, and values of -1, -2, or -3 correspond to a swingby passage distance initial guess of  $r_p = \infty$  (i.e., continuous heliocentric velocity). Each element MSWING(i) may have any of the following values:

- = - 1 Go\* directly for unpowered swingby; if and only if it fails, go for powered swingby having flight time T2(i) = initial guess.
- = - 2 Go directly for powered swingby only, having T2(i) = flight time, of post-swingby leg.
- = - 3 Go directly for unpowered swingby; then, whether it succeeds or not, go for powered swingby having T2(i) = flight time.
- = - 4 Go directly for unpowered swingby, but using initial velocity guess loaded into XSWING(j, i), j = 1, 2, 3, similar to MSWING(i) = - 1.
- = - 5 Same as = - 2, except use initial guess as in = - 4.

\*"Go for" means "attempt to obtain (solution)".

Related to MOPT4, T2, XSWING, and NSWING.

## MTMASS

Mission-type selector pertaining to the primary target.

= 0 Flyby mission

- 1 Orbiter (high-thrust retro-maneuver without velocity loss).

(Continued on next page).

- MTMASS  
(cont)
- = 2 Orbiter (high-thrust retro-maneuver with velocity loss).
  - 3 Specified arrival excess speed  $v_{\infty}$ .
    - If  $v_{\infty} = 0$ , rendezvous mission
    - If  $v_{\infty} > 0$ , controlled flyby mission
    - No retro-maneuver in either case.
  - 4 Orbiter (Electric propulsion system performs spiral maneuver. Arrival excess speed  $v_{\infty}$  must be specified as zero).

Other parameters which may be related to MTMASS are DMRETR, CTRET, RPER, RAP, THRET, SPIRET, JPP, and JT.

MUPDAT Flag indicating whether iterator independent variables at end of one case are to be used as first guesses for next case.

= 0 Use input initial guesses.

- 1 Use independent variables of previous case as first guesses.

MYEAR Year of reference date (e.g., 1982). Related to MONTH, MDAY, and HOUR.

NDIST Identification number of celestial body to be used as the reference for the communication distance and angle measurement printed in the Extremum Point Summary Table. Identification code is the same as for MOPT2.

NHUNG Maximum number of propulsion-corner-proximity occurrences allowed in a given iteration-sequence. Related to GAP.

NORMAL Automatic adjoint-variable scaling.

= 0 No action.

- 1 All  $\Lambda$  and  $\dot{\Lambda}$  are scaled such that  $\lambda_{\nu_0}$  becomes unity.

NPERF Identification number of end condition that is to be used as the performance index when employing the direct parameter optimization feature (Improve Mode). The identification code is the same as the  $i$  in the  $Y_i$  end condition array.

NPRINT Print selection flag. Permits selection of amount of printout desired on each case.

= 0 Print only the case summary.

1 Print switching point summary of final trajectory.

2 Print MINPUT and case setup.

4 Print trajectory summary on each iteration.

8 Print partial derivative matrix each iteration.

Combinations of options obtained by summing options desired. If  $NPRINT > 15$ , printout consistent with  $NPRINT = 0$  is obtained. If the sign of  $NPRINT$  is reversed to negative, the iterator independent and dependent variables additionally are printed for every trajectory which HILTOP generates (including neighboring trajectories).

NSET Iteration-sequence control array.

NSET(1) Not used for input.

NSET(2) Not used for input.

NSET(3) Maximum number of iterations permitted in attempting to satisfy (point) constraints in satisfy mode. If zero, no upper limit imposed.

NSET(4) Flag indicating whether (point) constraints are to be satisfied prior to entering improve mode.

= 0 Satisfy constraints first.

1 Proceed immediately to improve mode.

NSET(5) Maximum number of iterations permitted after entering improve mode. Setting  $NSET(5) = 1$  causes iterator to be bypassed and computes single trajectory to obtain printout.

NSWING	Swingby continuation analysis option indicator. When zero or positive, NSWING is the number of full revolutions which the post-swingby heliocentric trajectory must have, and subroutine ACONIC (not MINMX3) is used to obtain the solution. When negative, NSWING has the same definition as MSWING (which see), and the MINMX3 iterator is used; NSWING <u>must</u> be used when MOPT4(1) > 0, and <u>may</u> be used when MOPT4(1) < 0. If MOPT4(1) < 0 and MSWING(i) = 0, then MSWING(i) will be set to the value of NSWING. Related to MSWING, MOPT4 and T2.
NSWPAR	<p>Iterator independent-variable perturbation-increment control.</p> <p>= 0 No action.</p> <p>1 Allows the iterator to vary a given independent-variable perturbation <math>\Delta x</math> whenever a neighboring trajectory is detected which has a different number of thrust switch points than the associated nominal trajectory. <math>\Delta x</math> is varied until the same number of switch points is achieved.</p>
NTAPE	Specifies the unit-number for the trajectory tape. Pertains to when MPUNCH $\leq -101$ .
OMI	Ascending node angle (with respect to vernal equinox) of primary-target orbit. Input only when MOPT3 = 11. Related to CNI, ECI, SAI, SOI, TPI, EMUODD, and RADODD. [deg]
OMIX	Array of five elements, the first three of which may be currently used. Ascending node angles of intermediate-target orbits. Input OMIX(i) only when MOPTX(i) = 11. Related to CNIX, ECIX, SAIX, SOIX, TPIX, EMUODX, and RADODX. [deg]
POWFIX	Launch-vehicle-independent (i.e., no launch vehicle) trajectory option in which the value of POWFIX is the spacecraft's reference power. [kw]

PSIGN	Flag defining the sense of the launch hyperbolic excess velocity relative to the initial primer vector. A value of +1. results in the assignment of the geocentric right ascension of the excess velocity equal to that of the initial primer vector. A value of -1. causes the geocentric right ascension of the excess velocity to be 180 degrees from that of the initial primer.
RADODD	Radius of primary target. Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SAI, SOI, TPI, and EMUODD. [meters]
RADODX	Array of five elements pertaining to the radii of intermediate targets. These inputs are not used at present.
RAP	Apoapse distance of capture orbit about primary target. [planet radii]
REVS	Number of complete revolutions of the ballistic trajectory generated when the associated input MOPT is used. Must be a positive whole number.
RPER	Periapse distance of capture orbit about primary target. [planet radii]
SAI	Semi-major axis of primary-target orbit (must be positive). Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SOI, TPI, EMUODD, and RADODD. [AU]
SAIX	Array of five elements, the first three of which may be currently used. Semi-major axes of intermediate-target orbits (must be positive). Input SAIX(i) only when MOPTX(i) = 11. Related to CNIX, ECIX, OMX, SOIX, TPIX, EMUODX, and RADODX. [AU]
SOI	Argument of perihelion of primary-target orbit. Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SAI, TPI, EMUODD, and RADODD. [deg]
SOIX	Array of five elements, the first three of which may be currently used. Arguments of perihelion of intermediate-target orbits. Input SOIX(i) only when MOPTX(i) = 11. Related to CNIX, ECIX, OMX, SAIX, TPIX, EMUODX, and RADODX. [deg]

SPIRET	Retro-stage specific impulse (pertaining to the retro-maneuver at the primary target). [sec]
STATE	Array of six elements containing the Cartesian position and velocity components of the primary target. Use only when MOPT2 = 0 and the trigger settings of Y1(2) through Y6(2) are 0 or 1. [AU, AU/tau] (tau = 58.132440991 days)
STEP1	Thrust-phase computation step size, $\Delta u$ .
STEP2	Coast-phase computation step size, $\Delta \beta$ .
TCOAST	Array of twenty elements, consisting of the durations of the coast phases corresponding to the coast-phase start-times input in the associated array TOFF. [days]
TDV	Time of occurrence of an impulsive deep space burn, in days from the start of the trajectory, which may be used only if the entire trajectory is ballistic (i.e., electric propulsion is not permitted with this option, nor is a third intermediate target). Iterator independent variables X64, X65, and X66 must be turned on, as these are used as the $\Delta v$ vector components of the deep space burn in EMOS. Also, set MAXHAM = 0. The following special feature is available regarding a first intermediate-target. If $1.D5 < TDV < 2.D5$ , then the burn occurs (TDV - 1.D5) days after passage of that target; if $TDV > 2.D5$ , the burn occurs (TDV - 2.D5) days before passage of that target. [days]
TGO	Ballistic trajectory-extension print option. When zero, no action. When positive, TGO = the number of days that the trajectory is to extend ballistically beyond the primary-target when no swingby-continuation is requested, and ballistically beyond the (last) post-swingby target when swingby-continuation is requested (in addition to the post-swingby trajectory segment itself). Any negative value will invoke printout of only the post-swingby trajectory segment or segments when swingby-continuation is requested. Applies also to trajectories with multiple swingbys. [days]

THRET	Retro-stage thrust, used only when MTMASS = 2. [lbs]
TOFF	Array of twenty elements, consisting of the times, in days from the start of the trajectory, at which imposed coast phases are to begin. Times must be in ascending order. Related to TCOAST. [days]
TPI	Time from reference date (MYEAR, etc.) to perihelion passage, for the primary target. Input only when MOPT3 = 11. Related to CNI, ECI, OMI, SAI, SOI, EMUODD, and RADODD. [days]
TPIX	Array of five elements, the first three of which may be currently used. Times from reference date (MYEAR, etc.) to perihelion passages, for the intermediate targets. Input TPIX(i) only when MOPTX(i) = 11. Related to CNIX, ECIX, OMIX, SAIX, SOIX, EMUODX, and RADODX. [days].
TPOWER	Solar-cell degradation characteristic-time; nuclear electric propulsion radioactive-decay characteristic-time. Related to MPOW. [days]
TSCALE	Iterator dependent-variable tolerance-interval scaling factor; scales all tolerances multiplicatively by the amount TSCALE.
T2	Array of ten elements consisting of initial estimates of swingby-continuation trajectory-segment flight-times, i.e., T2(i) correspond to MOPT4(i). [days]
XANG1	Latitude of the launch site. Used only if LAUNCH is non-zero. Related to XANG2. [deg]
XANG2	Maximum parking orbit inclination, permitted by range safety considerations. Used only if LAUNCH is non-zero. Related to XANG1. [deg]
XSWING	Array of velocity vectors consisting of initial velocity guesses of a given post-swingby trajectory segment. Used only when either NSWING or MSWING has a value of -4 or -5. See especially the description of MSWING = -4. Velocity consists of exactly the same values as found in the V1, V2, V3 locations of the (Continued on next page).

XSWING (cont)	trajectory block print (first block). Related to MSWING, NSWING, MOPT4, and T2. [AU/tau]
X0	Array of seven elements, the first six of which contain the Cartesian position and velocity components of the launch planet. The seventh element is not used for input. Used only when MOPT2 = 0. [AU, AU/tau]

The following describes the iterator independent and dependent variable arrays of the boundary value problem. Input pertaining to the individual independent parameters is contained in the arrays X1 through X70. The independent-parameter arrays have five elements for each variable, as follows (where  $i = 1, 2, 3, \dots, 70$ ):

Xi(1)	Input value of parameter. Must be input regardless of trigger setting. If trigger is on (i.e., $Xi(2) = 1$ ), input value is used as initial guess of independent parameter and is varied at each subsequent iteration. If trigger is off, the parameter is not used as an independent parameter and is not changed.
Xi(2)	Trigger indicating whether parameter is to be an independent parameter in boundary value problem.  <div style="margin-left: 40px;"> <math>Xi(2) = 0</math> Not an independent parameter.              (Trigger is "off").   <div style="margin-left: 40px;"> <math>1</math> Use as independent parameter.              (Trigger is "on").           </div> </div>
Xi(3)	Maximum change to parameter permitted in a single iteration. Should be a positive quantity. Used only if trigger is on. Units are same as that of the parameter.
Xi(4)	Perturbation increment used to compute partial derivatives by finite differences. Used only if trigger is on. Units are same as that of the parameter.
Xi(5)	Weighting factor. Should be a positive quantity. A value of 1. is generally recommended. The larger the weighting factor, the more the parameter is inhibited from varying. Used only if trigger is on.



The independent variables are as follows:

X1	$\Lambda_o(1)$	} Initial primer vector.
X2	$\Lambda_o(2)$	
X3	$\Lambda_o(3)$	
X4	$\dot{\Lambda}_o(1)$	} Initial primer derivative.
X5	$\dot{\Lambda}_o(2)$	
X6	$\dot{\Lambda}_o(3)$	
X7	$\lambda_{\nu o}$	Initial mass-ratio adjoint-variable.
X8	$\lambda_{\tau}$	Propulsion-time adjoint-variable.
X9		Not used.
X10	$\delta$	Geocentric declination of launch hyperbolic excess velocity. [deg]

There is no conversion from input to internal units for any of the adjoint variables.

X11	Reference thrust acceleration, g. [m/sec <sup>2</sup> ]
X12	Electric propulsion system jet exhaust speed, c. [m/sec]
X13	Launch hyperbolic excess speed, $v_{\infty o}$ . [m/sec]
X14	Hyperbolic excess speed at primary target, $v_{\infty n}$ . [m/sec]
X15	Initial time, $t_o$ , measured from the reference date (MYEAR, etc.). [days]
X16	Time at the primary target, $t_n$ , measured from the reference date (MYEAR, etc.). [days]

X17		Launch parking orbit inclination, $i$ . Used only if LAUNCH $\neq 0$ . Optimized internally by the program if both X17 and Y17 triggers are off. [deg]
X18	$\dot{x}_0$	} Initial spacecraft heliocentric velocity. Not required unless one of the three triggers is on. [AU/tau] (tau = 58.132440991 days)
X19	$\dot{y}_0$	
X20	$\dot{z}_0$	
X21		Constant thrust cone-angle, $\phi$ . Non-zero value invokes the constant- $\phi$ constraint. $0 < \phi \leq 180^\circ$ . Zero-value implies that $\phi$ is optimized along the trajectory (variable $\phi$ ). [deg]

X22 through X29 are currently not used (although some locations following X21 are reserved for additional constant thrust cone-angles).

X30	$\lambda_s$	Degradation-time adjoint-variable.
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X31 through X40 are currently not used. X41 through X50 pertain to the first intermediate target, X51 through X60 pertain to the second intermediate target, and X61 through X70 pertain to the third intermediate target. The corresponding intermediate-target parameters are ignored if the intermediate target is absent. Subscripts 1, 2, and 3 pertain to the first, second, and third intermediate targets, respectively.

X41	$\Lambda_1(1)$	} Primer vector (at start of trajectory segment)
X42	$\Lambda_1(2)$	
X43	$\Lambda_1(3)$	
X44	$\dot{\Lambda}_1(1)$	} Primer derivative (at start of trajectory segment)
X45	$\dot{\Lambda}_1(2)$	
X46	$\dot{\Lambda}_1(3)$	

X47	Encounter speed at first intermediate target, $v_{\infty 1}$ . [m/sec]
X48	Time at the first intermediate target, $t_1$ , measured from the reference date (MYEAR, etc.). [days]
X49	Sample-mass factor, $k_{\text{samp } 1}$ , for sample- retrieval at first intermediate target.
X50	Drop-mass factor, $k_{\text{drop } 1}$ , for instrument- package dropoff at first intermediate target.

The independent variables X51 through X60 and X61 through X70 are identical to X41 through X50 except that they pertain to the second and third intermediate targets, respectively. A third intermediate target may not be present when simulating ballistic missions having a deep space burn (See TDV), in which case X64, X65, and X66 are used as follows:

X64	$\Delta \dot{x}$	} Deep-space velocity-increment. [AU/tau]
X65	$\Delta \dot{y}$	
X66	$\Delta \dot{z}$	

Inputs pertaining to the individual dependent parameters are contained in the arrays Y1 through Y70. The dependent-parameter arrays have three elements for each variable, as follows (where  $i = 1, 2, 3, \dots, 70$ ):

Yi(1)	Desired value of the dependent parameter.
Yi(2)	Trigger. If off (i.e., equal to zero), the parameter is ignored and is not considered a dependent parameter. Then the other two inputs pertaining to the parameter need not be input. If trigger is on (i.e., not equal to zero), the parameter is considered to be dependent parameter or constraint. Certain of the parameters may have

Yi(2) (cont)	up to three non-zero trigger settings. These will be discussed individually below.
Yi(3)	Tolerance of desired value (full interval width).

It should be noted that the transversality conditions, which comprise some of the parameters, are developed under the assumption that all constraints are of the point constraint type. Therefore, the satisfy-mode is sufficient in solving any optimization problems for which a complete set of transversality conditions is available.

The dependent-parameter arrays are as given below.  $T(x)$  represents "the transversality condition associated with  $x$ " and the function  $T(x)$  will have different values depending upon the constraints imposed on the problem. See NOMENCLATURE of reference [1] for definition of symbols and subscripts.

	<u>Trigger 1</u>		<u>Trigger 2</u>	<u>Trigger 3</u>	
Y1	$\Delta x_n$ [AU]	'	a [AU]	Solar distance* [AU]	$T(\sigma)$
Y2	$\Delta y_n$ [AU]	'	e	$T(\theta_t)^*$	$T(\theta_t)$
Y3	$\Delta z_n$ [AU]	'	i [deg]		$T(t_n)$
Y4	$\Delta \dot{x}_n$ [AU/tau]	'	$T(\Omega)$	$T(\dot{x}_n)$	$T(\xi)$
Y5	$\Delta \dot{y}_n$ [AU/tau]	'	$T(\omega)$	$T(\dot{y}_n)$	$v_{\infty 0}$
Y6	$\Delta \dot{z}_n$ [AU/tau]	'	$T(f)$	$T(\dot{z}_n)$	$T(\lambda)$
				optimal flyby	

NERVA

\*Applicable only for two-dimensional motion in the xy plane. Also requires that MOPT2 = 0.

Under Trigger 1 above, the first set of conditions applies to ordinary targeting conditions for position and velocity, and also to extra-ecliptic conditions to be satisfied when IOUT = 1; the second set of conditions applies to extra-ecliptic missions when IOUT = 2.  $T(\Omega)$ ,  $T(\omega)$ , and  $T(f)$  are symbols for the transversality

conditions yielding optimum final node angle, argument of perihelion, and true anomaly, respectively.

	<u>Trigger 1</u>	<u>Trigger 2</u>	<u>Trigger 3</u>
Y7	$\nu_n$	$\lambda \nu_n$	$m_{\text{net}}$ [kg]
Y8	$T(\tau)$	$\tau$ [days]	
Y9	Currently not used.		
Y10	$T(\delta)$	$\delta$ [deg]	Used only if LAUNCH $\neq 0$ .
Y11	$T(g)$	$g$ [m/sec <sup>2</sup> ]	$p_{\text{ref}}$ [kw]
Y12	$T(c)$	$c$ [m/sec]	
Y13	$T(v_{\infty 0})$	$v_{\infty 0}$ [m/sec]	
Y14	$T(v_{\infty n})$	$v_{\infty n}$ [m/sec]	extra-ecliptic inclination [deg]
Y15	$T(t_o)$	$t_o$ [days]	
Y16	$T(t_n)$	$t_n$ [days]	$t_n - t_o$ [days]*

\*Time transversality with flight time fixed is assigned to Y15 under trigger 1.

Y17	$T(i)$	$i$ [deg], where $i$ = parking orbit inclination.	Used only if LAUNCH $\neq 0$ .
Y18	$T(\dot{x}_o)$	$\dot{x}_o$ [AU/tau]	
Y19	$T(\dot{y}_o)$	$\dot{y}_o$ [AU/tau]	
Y20	$T(\dot{z}_o)$	$\dot{z}_o$ [AU/tau]	
Y21	$T(\phi)$	$\phi$ [deg] for $\phi =$ constant with time.	

Y22 through Y29 are currently not used.

Trigger 1      Trigger 2

Y30                      T(s)                      s [days]                      (Degradation time)

Y31 through Y40 are currently not used. Y41 through Y50 pertain to the first intermediate target.

Y41	$\Delta x_1$ [AU]	
Y42	$\Delta y_1$ [AU]	
Y43	$\Delta z_1$ [AU]	
Y44	$\Delta \dot{x}_1$ [AU/tau] , $T(\dot{x}_1)$	} optimal flyby
Y45	$\Delta \dot{y}_1$ [AU/tau] , $T(\dot{y}_1)$	
Y46	$\Delta \dot{z}_1$ [AU/tau] , $T(\dot{z}_1)$	
Y47		$v_{\infty 1}$ [m/sec]
Y48	$T(t_1)$	$t_1$ [days]
Y49	$m_{\text{samp } 1}$ [kg]	
Y50	$m_{\text{drop } 1}$ [kg]	

Y51 through Y60 and Y61 through Y70 are identical to Y41 through Y50 except that they pertain to the second and third intermediate targets, respectively.

### C. DEFAULT VALUES OF INPUT PARAMETERS

The following is a complete, alphabetical list of the default values of program input quantities having non-zero default values, except for the iterator arrays. All other inputs are zeroed. The default values of the iterator arrays  $X_i(1)$ ,  $X_i(2)$ ,  $Y_i(1)$ , and  $Y_i(2)$ , for  $i = 1, 2, 3, \dots, 70$ , are zero, and the default values of  $X_i(3)$  through  $X_i(5)$  and  $Y_i(3)$  for the same range of  $i$  are listed in the listing of program inputs of Sample Case C.

ALPHAA	15.	NSET(3)	300
ALPHAT	15.	NSET(5)	300
AN	1.5	NSWPAR	1
AR	1.	NTAPE	17
BI	.76	POWFIX	-1.
CTANK	.03	PSIGN	1.
CTRET	1/9	RADODD	1.
DI	13.	RAP	38.
GAMMAX	1.	RPER	2.
GAP	.0001	SAI	1.
HOURL	12.	SPIRET	300.
IRK	1	STATE(1)	1.
IRL	1	STATE(5)	1.
ITF	3	STEP1	.03125
MAXHAM	5	STEP2	.125
MDAY	1	TDV	-1.
MODE	4	TGO	-1.
MONTH	1	THRET	400.
MOPT3	10	TOFF	20*-1.
MUPDAT	1	TPOWER	10.**30
MYEAR	1975	TSCALE	1.
NDIST	3	T2(i)	50*i
NHUNG	25	X0(1)	1.
NPRINT	7	X0(5)	1.0000015

#### IV. SAMPLE PROBLEMS AND RESULTS

Three sample cases have been selected for presentation in the following pages. Each case was selected to display the use of one or more new features that have been added to the program. The first case is an extra-ecliptic mission that exhibits the effects of high launch asymptote declinations on launch vehicle performance and the low thrust trajectory. This case also displays the housekeeping power option that was recently added to the program. The second case is a comet rendezvous mission which includes the effects of solar array degradation due to radiation effects. The third and final case displays the HILTOP's powerful capability for ballistic mission design and optimization. The specific mission chosen is a cometary flyby past Giacobini-Zinner followed by a deep space burn 10 days after passage, a return to and swingby of Earth (unpowered), a second swingby of Earth (powered), and finally encountering the comet Borrelly nearly 1023 days from launch. The tremendous flexibility for creating imaginative, multi-target mission profiles is demonstrated in this example.

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#### A. EXTRA ECLIPTIC MISSION

The objective of this mission is to place maximum payload in a circular orbit of 1.001 AU radius inclined 45 degrees to the ecliptic. The mission is  $2\frac{1}{2}$  years (912.5 days) in duration and departs from Earth parking orbit on April 21, 1979. The solution given in this example is contained in the class of six-burn solutions which, for the mission duration assumed, tends to restrain the trajectory from deviating far from the nominal 1 AU solar distance. The specific case chosen uses the Titan III E/Centaur launch vehicle. The reference power (the power delivered to the power conditioners at 1 AU) is 20.35 kw and the specific impulse of the thrusters is 3000 seconds. The launch excess speed is optimized. The extra-ecliptic end conditions are invoked by setting IOUT = 1 and defining the desired values for AR, AE and AAI, the radius, eccentricity and inclination, respectively.

This case exhibits the use of several optional features of the program. A total of 0.65 kw of power developed by the solar arrays is reserved for housekeeping (non-propulsive) uses. This option is triggered with the input DPOW which is the ratio of housekeeping power to reference power. The power delivered to the power conditioners at distances below 1 AU is not permitted to exceed that delivered at 1 AU. This constraint is invoked by setting MODE equal to 5 and GAMMAX (the maximum permissible value of the power factor  $\gamma$ ) equal to 1. The effects of launch asymptote declination are included in the launch vehicle performance model by setting LAUNCH equal to 1. The equatorial inclination of the launch parking orbit is limited to a maximum of 36 degrees through the input parameter XANG2. Since the geocentric declination of the launch asymptote for extra ecliptic missions is usually much greater than this inclination limit, the solution will include a non-coplanar injection maneuver from the launch parking orbit. The declination of the launch asymptote is optimized. Finally, the option of inputting the coefficients of the power profile is illustrated. The inputs for this case are listed on the next page.

It should be noted that the choice of final orbit radius of 1.001 AU rather than 1.0 AU was made to alleviate numerical difficulties arising as a result of the corner in the power curve at 1 AU. Neighboring trajectories terminating on opposite sides of the corner point tend to possess different partial derivatives (i.e., they will behave differently when subjected to the same perturbation). Consequently, if the final desired distance is exactly the point of the discontinuity, one might expect convergence retardation when the end conditions are nearly satisfied.

```
&MINPUT X1(2)=1.00,X2(2)=1.00,X3(2)=1.00,X4(2)=1.00,X5(2)=1.00
X6(2)=1.00,X7=1.00,X10(2)=1.00,X11(2)=1.00,X12=2.94199504
X13(2)=1.00,X15=3.1037001,X16=9.4353702
Y1(2)=1.00,Y2(2)=1.00,Y3(2)=1.00,Y4(2)=1.00,Y5(2)=1.00,Y6(2)=1.00
Y10(2)=1.00,Y11=20.3500,3.00,Y13(2)=1.00
LAUNCH=1,MBOOST=15,MTMASS=3,MODE=5
MOPT2=3,MOPT3=0,MYEAR=1979,MONTH=3,MDAY=21
BI=.6300,DI=0.00,CTANK=.03500,GAMMAX=1.00,DPOW=3.1941031941030-2
IOUT=1,AAI=45.00,AR=1.00100,XANG1=28.500,XANG2=36.00
ASOL=1.438200,0.00,-.223500,0.00,-.214700
X1=-1.8492690168360-02,X2=-3.4445458696870-01,X3=-5.2928946808260 00
X4= 7.2838600516620-01,X5= 6.4899582772630-01,X6=-3.2776418049730-01
X10=-3.8091507295560 01,X11= 2.7905740612560-04,X13= 5.3286065346450 03
&END
```

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CASE 1

ITERATOR PARAMETERS

INDEPENDENT VARIABLES

NO.	INDEX	VALUE	STEP LIMIT	PERTURBATION	WEIGHT
1	1	-1.8492692168360000D-02	3.0000000000000000D-03	1.0000000000000000D-08	1.0000000000000000D-00
2	2	-3.4445456696870000D-01	3.0000000000000000D-03	1.0000000000000000D-08	1.0000000000000000D-00
3	3	-5.2928946808260000D-00	3.0000000000000000D-03	1.0000000000000000D-08	1.0000000000000000D-00
4	4	7.2839605168200000D-01	3.0000000000000000D-03	1.0000000000000000D-08	1.0000000000000000D-00
5	5	6.4899582772630000D-01	3.0000000000000000D-03	1.0000000000000000D-08	1.0000000000000000D-00
6	6	-3.2776418049730000D-01	3.0000000000000000D-03	1.0000000000000000D-08	1.0000000000000000D-00
7	10	-3.8091507295560000D-01	9.0000000000000000D-01	9.9999999999999990D-37	1.0000000000000000D-00
8	11	2.7905740612559990D-04	9.9999999999999990D-04	1.0000000000000000D-11	1.0000000000000000D-00
9	13	5.3296065346449990D-03	5.0000000000000000D-02	9.9999999999999990D-05	1.0000000000000000D-00

DEPENDENT VARIABLES

NO.	INDEX	VALUE	TOLERANCE
1	1	0.0	9.9999999999999990D-05
2	2	0.0	9.9999999999999990D-05
3	3	0.0	9.9999999999999990D-05
4	4	0.0	9.9999999999999990D-05
5	5	0.0	9.9999999999999990D-05
6	6	0.0	9.9999999999999990D-05
7	10	0.0	9.9999999999999990D-05
8	11	2.0350000000000000D-01	9.9559999999999990D-05
9	13	0.0	9.9999999999999990D-05

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----- NOMINAL TRAJECTORY 1 (TOTAL 1) ----- INHIBITOR IS 5.8208D-11 -----

INDEPENDENT PARAMETERS

1.PRIM1(-1.8492690D-02) 2.PRIM2(-3.4434549D-01) 3.PRIM3(-5.2925947D 00) 4.PDOT1( 7.2838601D-01) 5.PDOT2( 6.4895583D-01)  
6.PDOT3(-3.2776418D-01) 10.DECLN(-3.8091507D 01) 11.ACCEL( 2.7905741D-04) 13.VINFI( 5.3286065D 03)

DEPENDENT PARAMETERS

1.DELTA X( 1.36734D-02) 2.DELTA Y(-2.04257D-02) 3.DELTA Z( 2.52203D-02) 4.DELT XD( 1.62397D-02) 5.DELT YD(-2.40807D-02)  
6.DELT ZD( 2.57904D-02) 10.T.DECLN( 1.75024D-09) 11.POWER( 2.03500D 01) 13.T.VINFI(-3.71296D-09)  
THRUST SWITCHING TIMES (DAYS) 0.0 ON 103.276 ON 218.909 OFF 247.259 ON 399.777 OFF  
439.175 ON 567.999 OFF 618.895 ON 749.493 OFF 839.322 ON 912.530 ON

ELECTRIC PROPULSION PARAMETERS

PROP TIME J  
712.1252770929 11.3661826370  
MASS COMPONENT BREAKDOWN  
PROPELLANT TANKAGE  
1813.3820629241 63.4683722023

EFFICIENCY 0.6300000000  
PROPULSION 620.249999709  
INITIAL 3123.1976935923

POWER 20.3499999990  
AVE ACCEL 0.0004309116  
PAYLOAD 626.0972584950

----- NOMINAL TRAJECTORY 2 (TOTAL 4) ----- INHIBITOR IS 1.8190D-12 -----

INDEPENDENT PARAMETERS

1.PRIM1(-9.0058542D-03) 2.PRIM2(-3.5175913D-01) 3.PRIM3(-5.2008632D 00) 4.PDOT1( 6.9910970D-01) 5.PDOT2( 6.2888718D-01)  
6.PDOT3(-3.3398207D-01) 10.DECLN(-3.7843959D 01) 11.ACCEL( 2.6655743D-04) 13.VINFI( 5.1101377D 03)

DEPENDENT PARAMETERS

1.DELTA X(-1.06725D-05) 2.DELTA Y(-9.99850D-04) 3.DELTA Z(-2.51110D-03) 4.DELT XD( 1.14983D-03) 5.DELT YD(-7.22438D-04)  
6.DELT ZD( 2.13528D-03) 10.T.DECLN( 2.70967D-03) 11.POWER( 2.03067D 01) 13.T.VINFI(-1.69061D-03)  
THRUST SWITCHING TIMES (DAYS) 0.0 ON 103.651 ON 219.584 OFF 247.918 ON 400.527 OFF  
439.396 ON 566.714 OFF 616.029 ON 747.829 OFF 804.878 ON 912.500 ON

ELECTRIC PROPULSION PARAMETERS

PROP TIME J  
715.6762058950 9.8909155678  
MASS COMPONENT BREAKDOWN  
PROPELLANT TANKAGE  
1819.7281211922 63.5904842417

EFFICIENCY 0.6300000000  
PROPULSION 618.9289536062  
INITIAL 3262.5709661616

POWER 20.3066573251  
AVE ACCEL 0.0004008460  
PAYLOAD 760.2234071214

----- NOMINAL TRAJECTORY 3 (TOTAL 7) ----- INHIBITOR IS 5.6843D-14 -----

INDEPENDENT PARAMETERS

1.PRIM1( 2.2736015D-03) 2.PRIM2(-3.7436282D-01) 3.PRIM3(-5.1922367D 00) 4.PDOT1( 7.0903573D-01) 5.PDOT2( 6.3603250D-01)  
6.PDOT3(-3.2226660D-01) 10.DECLN(-3.7854840D 01) 11.ACCEL( 2.6660044D-04) 13.VINFI( 5.0985903D 03)

DEPENDENT PARAMETERS

1.DELTA X( 9.71723D-04) 2.DELTA Y(-4.33226D-04) 3.DELTA Z(-1.01801D-03) 4.DELT XD(-5.13986D-04) 5.DELT YD( 4.32699D-05)  
6.DELT ZD( 3.84511D-04) 10.T.DECLN(-3.74522D-05) 11.POWER( 2.03500D 01) 13.T.VINFI( 3.24076D-05)  
THRUST SWITCHING TIMES (DAYS) 0.0 ON 103.546 ON 220.043 OFF 248.369 ON 400.927 OFF  
439.925 ON 568.200 OFF 617.759 ON 749.422 OFF 836.781 ON 912.530 ON

ELECTRIC PROPULSION PARAMETERS

PROP TIME J  
715.0113526675 9.8704919992  
MASS COMPONENT BREAKDOWN  
PROPELLANT TANKAGE  
1821.6164813205 63.7565768462

EFFICIENCY 0.6300000000  
PROPULSION 620.2492284722  
INITIAL 3269.1258074603

POWER 20.34999746867  
AVE ACCEL 0.0004006508  
PAYLOAD 763.5035208214

THIS CASE IS CONVERGED.

8 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND 3 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

CASE 1

## SWITCH POINT SUMMARY

PAGE 1

TIME	SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	NODE	ARG POS	RMAG	MASS RATIO	TRAVEL
R1	R2	R3	V1	V2	V3	L7	L7	THRUST ACC
L1	L2	L3	L4	L5	L6	POWER FNCT	PROP TIME	
LG	LC	LPHI	CONE	CLOCK	HMAG			
PSI	THETA	PHI	LATITUDE	LONGITUDE	FLT PTH ANG-E			

EARTH

## START OF TRAJECTORY, THRUST ON

0.0	8.989777750-01	1.211808740-01	9.228427590 00	3.093485450 01	1.900000000 02	1.004982350 00	0.0	
-8.629263390-01	-5.151190790-01	0.0	4.964306950-01	-7.801992670-01	-1.501859510-01	1.000000000 00	0.0	
1.433022090-03	-3.712734700-01	-5.192223320 00	7.085911630-01	6.352863480-01	-3.284391610-01	1.000000000 00	0.0	
0.0	0.0	0.0	8.605271660 01	1.713665910 01	9.411569810-01	9.930951630-01	0.0	
-7.708403020 01	8.064814240 01	8.791846720 01	0.0	-1.491651460 02	-1.612086370 00	9.3686518580-01	0.0	

## SWITCH THRUST OFF

8.033831620 01	9.240153250-01	1.030222170-01	1.196780310 01	4.065933450 01	2.527328480 02	8.894437360-01	8.236967300 01	
3.411006150-01	-8.023345320-01	-1.761244690-01	9.423323710-01	5.255348160-01	-4.562449540-02	9.371125330-01	4.798246700-02	
3.977283740-01	-4.694863440-02	-1.119306190 00	-4.701773370-02	-6.320616820-01	5.367113510 00	1.253030110 00	9.491115210-02	
-3.874798870 00	-7.301637330-02	0.0	9.740795070 01	1.511051620 01	9.561423620-01	1.000000000 00	-3.996802890-15	
-6.041975990 01	4.478400230 01	6.948999100 01	-1.142099890 01	-6.696794930 01	-5.512069660 00	1.079983000 00	8.033831620 01	

## SWITCH THRUST ON

1.035874760 02	9.240153250-01	1.030222170-01	1.196780310 01	4.065933450 01	2.527328480 02	8.894437360-01	8.236967300 01	
6.631257300-01	-5.070083970-01	-1.731113720-01	6.287177060-01	9.298308850-01	6.258344780-02	9.371125330-01	4.798246700-02	
4.073275130-01	-3.994121780-01	1.042972960 00	1.311270360-01	-1.050125490 00	5.227605910 00	1.253030110 00	9.491115210-02	
-3.874798870 00	-7.301637330-02	0.0	9.047700790 01	1.748343320 02	9.561423620-01	1.000000000 00	-1.332267630-15	
7.321791110 01	-3.521547950 00	7.325053520 01	-1.171610550 01	-3.740057220 01	-3.910803900 00	1.124188860 00	8.033831620 01	

## SWITCH THRUST OFF

2.200471310 02	9.268122330-01	9.308915210-02	1.575481410 01	4.107520600 01	7.031145360 01	9.295082010-01	2.602805930 02	
-3.173520540-01	8.407180210-01	2.376255520-01	-8.845399570-01	-2.997231950-01	1.199697730-01	8.459144480-01	5.315545950-02	
-2.433252570-01	-6.420144370-01	1.197578380 00	-8.530832780-01	4.973095690-01	-4.746233360 00	1.611883020 00	9.491116750-02	
-8.084407140 00	-2.048093540-01	0.0	9.927457730 01	1.629975860 02	9.585305720-01	1.000000000 00	-1.754152380-14	
6.398730370 01	1.084350530 02	9.797198290 01	1.481196260 01	1.106803880 02	5.338755550 00	1.035716310 00	1.967979720 02	

## SWITCH THRUST ON

2.484149390 02	9.268122330-01	9.308915210-02	1.575481410 01	4.107520600 01	7.031145360 01	9.295082010-01	2.602805930 02	
-7.321702290-01	5.854702850-01	2.602350640-01	-6.831248370-01	-7.137296640-01	-2.516424950-02	8.459144480-01	5.315545950-02	
-5.741624170-01	-3.784338420-01	-1.196959740 00	-4.7408716210-01	5.857416210-01	-4.833448440 00	1.611883020 00	9.491116750-02	
-8.084407140 00	-2.048093540-01	0.0	8.594777300 01	3.685644790 01	9.585305720-01	1.000000000 00	2.886579860-15	
-5.849641790 01	9.923817760 01	9.481219310 01	1.551429030 01	1.413528820 02	4.518388020 00	9.882827610-01	1.967979720 02	

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TIME	SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	NODE	ARG POS	RMAG	TRAVEL
R1	R2	R3	V1	V2	V3	MASS RATIO	THRUST ACC
L1	L2	L3	L4	L5	L6	L7	HAN
LG	LC	LPHI	CONE	CLOCK	HMAG	POWER FNCT	SWITCH FNCT
PSI	THETA	PHI	LATITUDE	LONGITUDE	FLT PTM ANGLE	VMAG	PROP TIME
4.010070630 02	9.928792430-01	4.021556660-02	2.212696930 01	3.931884210 01	2.4798657700 02	9.758854130-01	4.361040980 02
2.480741360-01	-8.801594050-01	-3.407799650-01	9.467874783-01	3.537871210-01	-1.313635680-01	7.276817250-01	6.179208530-02
2.355275990-01	2.135501880-01	-1.692560920 00	4.523715290-01	-1.130723800 00	4.556849810 00	2.337641390 00	9.491117440-02
-1.559122360 01	-4.386962160-01	0.0	9.627615370 01	9.556487680 00	9.9562271730-01	1.000000000 00	-2.220446050-16
-6.505315360 01	4.903001100 01	7.456609170 01	-2.043384013 01	-7.425943680 01	-2.085943000 00	1.020906030 00	3.493900950 02

## SWITCH THRUST OFF

## SWITCH THRUST ON

4.399952240 02	9.928792430-01	4.021556660-02	2.212696930 01	3.931884210 01	2.4798657700 02	9.758854130-01	4.361040980 02
7.724348930-01	-4.500324890-01	-3.407799650-01	9.467874783-01	3.537871210-01	-1.313635680-01	7.276817250-01	6.179208530-02
6.064626370-01	-7.884010370-01	1.405868520 00	6.783913500-01	-1.540980790 00	4.292900070 00	2.337641390 00	9.491117440-02
-1.559122360 01	-4.386962160-01	0.0	1.006179130 02	1.827083360 02	9.9562271730-01	1.000000000 00	-1.421095470-14
7.682147830 01	-2.349917260 01	7.793166960 01	-2.085521473 01	-3.022573790 01	-9.631423060-01	1.040894360 00	3.493900950 02

## SWITCH THRUST OFF

## SWITCH THRUST ON

5.681922520 02	9.928792430-01	4.021556660-02	2.212696930 01	3.931884210 01	2.4798657700 02	9.758854130-01	4.361040980 02
-1.506807640-01	8.836263620-01	4.238659990-01	-9.469304813-01	-2.402550930-01	2.248543780-01	6.272922520-01	7.168108630-02
2.747517860-01	-8.126470770-01	1.796782390 00	-1.208023700 00	1.539216380 00	-3.874477950 00	3.135158230 00	9.491117390-02
-2.149807820 01	-7.147457240-01	0.0	7.881195510 01	1.826645970 02	9.936629950-01	1.000000000 00	-1.998401440-15
8.021703660 01	8.963810900 01	8.993850920 01	2.530774530 01	9.967733200 01	1.831364300 00	1.002476670 00	4.775871220 02

## SWITCH THRUST OFF

## SWITCH THRUST ON

6.177877340 02	9.928792430-01	4.021556660-02	2.212696930 01	3.931884210 01	2.4798657700 02	9.758854130-01	4.361040980 02
-8.126352050-01	3.984400910-01	4.475007380-01	-5.133137410-01	-8.222761690-01	-1.632743930-01	6.272922520-01	7.168108630-02
-7.596514920-01	6.687596400-01	-1.714643090 00	-1.113357330 00	1.737417860 00	-3.874477950 00	3.135158230 00	9.491117390-02
-2.149807820 01	-7.147457240-01	0.0	7.332521910 01	3.489896040 00	9.936629950-01	9.866692860-01	0.0
-8.496792010 01	4.865684340 01	8.667838360 01	2.630982233 01	1.538810000 02	8.167061320-01	9.842745950-01	4.775871220 02

## SWITCH THRUST OFF

7.496209950 02	1.008048750 00	1.322286570-02	3.667914110 01	3.858489670 01	2.399107740 02	9.988970520-01	7.869761060 02
4.073346740-02	-8.540298070-01	-5.164970410-01	9.313290730-01	2.349064760-01	-2.3961152850-01	5.254455040-01	8.557494710-02
-6.461998620-01	8.699006430-01	-2.032552950 00	1.220095780 00	-1.967002170 00	3.568784520 00	4.329961250 00	9.491117310-02
-2.835803440 01	-1.095770480 00	0.0	1.072342150 02	3.475754720 02	1.003928530 00	1.000000000 00	-1.332267630-15
-8.130255870 01	3.6254483640 01	8.299592590 01	-3.1115573320 01	-8.726931260 01	-5.508538470-01	1.005083490 00	6.094203940 02

TIME	SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	NODE	ARG POS	RMAG	MASS RATIO	TRAVEL
R1	R2	R3	V1	V2	V3	L7	L7	THRUST ACC
LI	L2	L3	L4	L5	L6	POWER FNCT	POWER FNCT	HAM
LG	LC	LPHI	CONE	CLOCK	HMAG	VMAG	VMAG	SWITCH FNCT
PSI	THETA	PHI	LATITUDE	LONGITUDE	FLT PTM	ANGLE	ANGLE	PROP TIME
8.069674900 02	1.008048750 00	1.322286570 02	3.669791410 01	3.858889670 01	2.971215400 02	9.949174200 01	9.949174200 01	8.441868720 02
7.973548400 01	-2.721259110 01	-5.291818420 01	4.738377590 01	8.478079300 01	2.736805820 01	5.254455040 01	5.254455040 01	8.557494710 02
7.835617570 01	-1.429434320 00	1.627366430 00	1.502294470 00	-2.195337040 00	3.286782330 00	4.329961250 00	4.329961250 00	9.491117310 02
-2.835893440 01	-1.095770480 00	0.0	1.135914370 02	1.956872790 02	1.003928530 00	1.000000000 00	1.000000000 00	-2.220446050 16
7.946959820 01	-6.863345320 01	8.618216410 01	-3.213291830 01	-1.394404610 01	1.300956420 01	1.009059750 00	1.009059750 00	6.094203840 02

SWITCH THRUST ON

INPUT TARGET

END OF TRAJECTORY, THRUST ON

9.125000000 02	1.001065380 00	9.482929380 05	4.499978360 01	3.676237590 01	4.278717760 01	1.000974630 00	1.000974630 00	9.482619080 02
3.007513090 01	8.248284640 01	4.807877500 01	-8.543975790 01	9.158705550 03	5.196863550 01	4.428474530 01	4.428474530 01	1.013985430 01
1.219411480 00	-1.874468100 00	2.728663000 00	-1.264304910 00	1.820503340 00	-2.369610530 00	5.782196730 00	5.782196730 00	9.491117590 02
-3.470770810 01	-1.512336690 00	0.0	7.320874720 01	2.321395460 02	1.000532540 00	9.986459540 01	9.986459540 01	9.355199940 01
8.381241470 01	6.962279920 01	8.784916900 01	2.870627380 01	6.996698860 01	-1.594932950 03	9.995583450 01	9.995583450 01	7.149528940 02

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## CASE 1

## ITERATOR SUMMARY

## INDEPENDENT PARAMETERS

1.PRIM1( 1.4330221D-03)	2.PRIM2(-3.7127347D-01)	3.PRIM3(-5.1922233D 00)	4.PDPT1( 7.0855915D-01)	5.PDPT2( 6.3528535D-01)
6.PDPT3(-3.2643916D-01)	7.LMASS( 1.0000000D 00)	8.LTAJ( 0.0 )	9. ( 0.0 )	10.DECLN(-3.7853674D 01)
11.ACCEL( 2.6684805D-04)	12.V JET( 2.9419950D 04)	13.VINF1( 5.0995285D 03)	14.VINF2( 0.0 )	15.TIME1( 3.1037000D 01)
16.TIME2( 9.4353700D 02)	17.PARK( 0.0 )	18.VE-31( 0.0 )	19.VEL2( 0.0 )	20.VELO3( 0.0 )
21.TMET1( 0.0 )	22.TMET2( 0.0 )	23.TMET3( 0.0 )	24.TMET4( 0.0 )	25.TMET5( 0.0 )
26.TMET6( 0.0 )	27.TMET7( 0.0 )	28.TMET8( 0.0 )	29.TMET9( 0.0 )	30.LDEGR( 0.0 )
31. PHI1( 0.0 )	32. PHI2( 0.0 )	33. P413( 0.0 )	34. PHI4( 0.0 )	35. PHI5( 0.0 )
36. PHI6( 0.0 )	37. PHI7( 0.0 )	38. P413( 0.0 )	39. PHI9( 0.0 )	40.PHI10( 0.0 )
41.PRI-A( 0.0 )	42.PR2-A( 0.0 )	43.PR3-A( 0.0 )	44.POI-A( 0.0 )	45.PD2-A( 0.0 )
46.PD3-A( 0.0 )	47.VINF1( 0.0 )	48.TIME1( 0.0 )	49.KSAMP( 0.0 )	50.KDROPI( 0.0 )
51.PRI-B( 0.0 )	52.PR2-B( 0.0 )	53.PR3-B( 0.0 )	54.POI-B( 0.0 )	55.PD2-B( 0.0 )
56.PD3-B( 0.0 )	57.VINF1( 0.0 )	58.TIME3( 0.0 )	59.KSAMP( 0.0 )	60.KDROPI( 0.0 )
61.PRI-C( 0.0 )	62.PR2-C( 0.0 )	63.PR3-C( 0.0 )	64.POI-C( 0.0 )	65.PD2-C( 0.0 )
66.PD3-C( 0.0 )	67.VINF1( 0.0 )	68.TIMEC( 0.0 )	69.KSAMP( 0.0 )	70.KDROPI( 0.0 )

## DEPENDENT PARAMETERS

1.0ELTA X( 3.62559D-05)	2.0ELTA Y(-1.85804D-05)	3.0ELTA Z(-4.36244D-05)	4.0ELT XD(-4.20018D-05)	5.0ELT YD( 2.21776D-05)
6.0ELT ZD( 4.21362D-05)	7. ( 0.0 )	8. ( 0.0 )	9. ( 0.0 )	10.T.DECLN( 5.77598D-07)
11. POWER ( 2.03500D 01)	12. ( 0.0 )	13.T.VIN=1(-1.61358D-06)	14. ( 0.0 )	15. ( 0.0 )
16. ( 0.0 )	17. ( 0.0 )	18. ( 0.0 )	19. ( 0.0 )	20. ( 0.0 )
21. ( 0.0 )	22. ( 0.0 )	23. ( 0.0 )	24. ( 0.0 )	25. ( 0.0 )
26. ( 0.0 )	27. ( 0.0 )	28. ( 0.0 )	29. ( 0.0 )	30. ( 0.0 )
31. ( 0.0 )	32. ( 0.0 )	33. ( 0.0 )	34. ( 0.0 )	35. ( 0.0 )
36. ( 0.0 )	37. ( 0.0 )	38. ( 0.0 )	39. ( 0.0 )	40. ( 0.0 )
41. ( 0.0 )	42. ( 0.0 )	43. ( 0.0 )	44. ( 0.0 )	45. ( 0.0 )
46. ( 0.0 )	47. ( 0.0 )	48. ( 0.0 )	49. ( 0.0 )	50. ( 0.0 )
51. ( 0.0 )	52. ( 0.0 )	53. ( 0.0 )	54. ( 0.0 )	55. ( 0.0 )
56. ( 0.0 )	57. ( 0.0 )	58. ( 0.0 )	59. ( 0.0 )	60. ( 0.0 )
61. ( 0.0 )	62. ( 0.0 )	63. ( 0.0 )	64. ( 0.0 )	65. ( 0.0 )
66. ( 0.0 )	67. ( 0.0 )	68. ( 0.0 )	69. ( 0.0 )	70. ( 0.0 )

THRUST SWITCHING TIMES (DAYS)	0.0	ON	80.338	OFF	103.587	ON	223.047	OFF	248.415	ON	401.007	OFF
439.995	ON	568.192	OFF	617.788	ON	749.621	OFF	836.967	ON	912.530	ON	

POWER	20.34999990796	EFFICIENCY	0.6300000000	PROP TIME	714.9528938345	PROP TIME	9.8696171166	PROP TIME	0.7835103206	AVE ACCEL	0.0004006926
INITIAL	3268.5460092059	PROPULSION	620.2499719473	PROPELLANT	1821.0787330785	PROPELLANT	63.7377556577	STRUCTURE	0.0	PAYLOAD	763.4795485224

SWITCH-COUNT HISTORY ALL 12

422 THRUST COMPUTE STEPS. 32 COAST COMPUTE STEPS

LAUNCH ASYMPTOTE OFFSET FROM PRIMER = -32.786 DEGREES.

CASE 1

## EXTREMUM POINTS J= SELECTED FUNCTIONS

I	TIME	ECLIPTIC LONGITUDE	SOLAR DISTANCE	COMMUNICATION ANGLE	SWITCH FUNCTION	PSI	THRUST ANGLES THETA	PHI	INPUT POWER	ARRAY ANGLE
0	0.0	0.0	1.005	75.7	ON 4.130 00	-77.1	80.5	87.9	20.2	0.0
4	1.065	1.0	1.004	75.3	ON 4.130 00	-77.1	80.5	87.9	20.2	0.0
5	8.379	7.6	1.000	72.6	MAX 4.150 00	-77.2	79.6	87.7	20.3	0.0
4	8.428	7.7	1.000	72.5	4.130 00	MIN -77.2	79.5	87.7	20.3	0.7
4	80.338	82.2	0.889	52.3	OFF -4.030-15	-60.4	44.8	69.5	20.3	37.7
6	91.933	96.6	0.870	51.4	MIN -7.450-01	*****	*****	*****	0.0	90.0
7	99.677	106.6	0.858	51.3	-3.230-01	*****	*****	*****	0.0	90.0
5	103.587	111.8	0.853	51.3	ON -1.330-15	73.2	-3.5	73.3	20.3	43.4
4	136.984	156.9	0.830	54.2	2.330 00	85.4	-80.5	89.2	20.3	46.5
4	159.653	186.8	0.840	51.0	MAX 2.930 00	87.2	-133.4	91.9	20.3	45.1
5	165.388	194.2	0.846	57.6	2.900 00	MAX 87.3	-154.1	92.4	20.3	44.4
4	220.047	259.8	0.930	62.3	OFF -1.730-14	64.0	108.4	98.0	20.3	30.2
8	234.249	275.5	0.952	63.3	MIN -7.090-01	*****	*****	*****	0.0	90.0
5	248.415	290.5	0.973	64.5	ON 2.330-15	-58.5	99.2	94.8	20.3	18.8
4	257.189	299.5	0.984	65.3	MAX 6.530-01	-68.1	97.2	92.7	20.3	14.5
4	272.871	314.9	1.000	66.7	1.740 00	-74.7	93.7	91.0	20.3	0.0
5	315.469	353.8	1.019	70.4	3.170 00	MIN -78.1	84.3	88.8	19.3	0.0
4	316.969	355.2	1.019	70.5	3.490 00	-78.1	84.0	88.8	19.8	0.0
5	325.138	362.3	1.018	70.9	MAX 3.530 00	-78.0	82.1	88.4	19.8	0.0
4	335.882	371.8	1.016	71.1	0.70	-77.7	79.5	86.2	19.9	0.0
4	356.876	390.7	1.006	70.3	2.930 00	-76.5	73.5	85.2	20.2	0.0
3	366.544	399.8	1.000	69.5	2.330 00	-75.6	70.3	85.2	20.3	0.0
6	401.007	434.9	0.976	65.2	OFF -2.220-16	-66.1	49.0	74.6	20.3	17.8
6	420.432	456.6	0.965	62.8	MIN -1.240 00	*****	*****	*****	0.0	90.0
5	439.995	478.9	0.957	61.1	ON -1.120-14	76.8	-23.5	77.9	20.3	23.8
4	461.762	503.1	0.953	60.2	1.520 00	83.1	-60.5	86.6	20.3	24.6
4	467.030	508.7	0.954	60.2	1.310 00	83.8	-67.2	87.6	20.3	24.6
5	476.946	518.9	0.955	60.3	MAX 2.270 00	84.9	-78.6	89.0	20.3	24.3
4	503.064	544.6	0.962	61.2	0.97 MAX	87.6	-115.3	91.0	20.3	22.2
6	509.882	551.0	0.965	61.5	MIN 2.790 00	88.1	-133.9	91.3	20.3	21.4
5	518.520	559.2	0.969	61.8	2.510 00	MAX 88.5	-172.2	91.5	20.3	20.3
4	529.847	570.1	0.974	62.1	2.250 00	87.8	139.0	91.6	20.3	18.5
4	544.170	584.0	0.980	62.3	1.530 00	86.0	111.0	91.4	20.3	16.0
4	568.192	608.8	0.992	61.9	OFF -2.000-15	80.2	89.6	89.9	20.3	10.5
5	598.100	630.6	1.000	61.3	MIN -1.510 00	*****	*****	*****	0.0	90.0
6	593.002	636.1	1.002	61.2	1.720 00	*****	*****	*****	0.0	90.0
5	604.245	648.5	1.006	61.1	1.040 00	*****	*****	*****	0.0	90.0
5	613.892	658.9	1.009	61.2	MAX -2.920-01	*****	*****	*****	0.0	90.0
6	617.788	663.0	1.010	61.3	ON 0.3	-85.0	48.7	86.7	20.1	0.0
5	633.894	679.4	1.013	62.1	1.100 00	MIN -87.1	42.5	87.9	20.0	0.0
5	631.984	696.2	1.015	63.6	2.040 00	-87.6	48.8	88.4	19.9	0.0
4	658.478	701.9	1.015	64.3	2.280 00	-87.5	52.6	88.5	19.9	0.0
4	668.726	710.5	1.014	65.4	2.350 00	-87.4	57.8	88.6	19.9	0.0
6	683.476	722.6	1.013	66.8	MAX 2.710 00	-86.8	62.1	88.5	20.0	0.0
7	692.955	730.2	1.011	67.4	2.550 00	-86.3	62.5	88.3	20.0	0.0
4	704.384	739.6	1.009	67.4	2.410 00	-85.6	61.9	87.9	20.1	0.0
6	711.876	745.9	1.007	67.6	2.150 00	-85.1	60.3	87.6	20.1	0.0
4	743.566	775.5	1.000	64.5	4.290-01	-82.3	42.9	84.3	20.3	0.0
4	749.621	781.9	0.999	63.6	OFF -1.330-15	-81.3	36.3	83.0	20.3	3.8
6	778.265	815.8	0.995	59.6	MIN -2.000 00	*****	*****	*****	0.0	90.0
5	796.948	838.7	0.995	58.1	ON -7.510-01	*****	*****	*****	0.0	90.0
6	806.967	850.3	0.995	57.8	2.220-16	79.5	-68.5	86.2	20.3	8.2
5	809.171	852.8	0.995	57.8	1.04	80.1	-70.6	86.7	20.3	8.1
4	810.095	853.8	0.995	57.8	1.570-01	80.3	-71.4	86.9	20.3	8.0
4	857.824	896.6	1.000	62.1	2.220-01	88.4	-116.9	90.7	20.3	2.3
5	863.133	900.6	1.000	62.8	2.230 00	89.1	-136.6	90.7	20.3	0.0
4	866.463	903.1	1.000	63.3	MAX 2.340 00	89.4	-165.0	90.6	20.3	0.0
5	868.262	904.4	1.000	63.5	2.340 00	86.2	81.6	89.5	20.3	0.0
5	895.587	924.9	1.001	65.7	1.750 00	86.1	81.6	89.4	20.3	0.0
5	896.651	925.8	1.001	65.7	1.710 00	86.1	79.8	89.3	20.3	0.0
4	898.104	926.9	1.001	65.7	1.550 00	85.9	79.8	89.3	20.3	0.0
5	912.500	939.1	1.001	65.1	ON 9.330-01	83.8	69.6	87.8	20.3	0.0

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# MISSION SCHEDULE

APRIL 21, 1979 1.288800000 01 G.M.I.  
2443252.0370 00 JULIAN DATE

DEPART EARTH

X	Y	Z	XDOT	YDOT	ZDOT	RADIUS	LAT.	LONG.
PLANET -8.6292634D-01	-5.1511908D-01	0.0	4.9631842D-01	-8.6241113D-01	0.0	1.0049824D 00	0.0	-149.165
S/C -8.6292634D-01	-5.1511908D-01	0.0	4.9543363D-01	-7.8019927D-01	-1.5013595D-01	1.0049824D 00	0.0	-149.165

CASE 1 (CONVERGED)

PERFORMANCE SUMMARY

OUT OF ECLIPTIC MISSION

FINAL INCLINATION = 44.9998 DEG

LAUNCH VEHICLE IS TITAN III E/CENTAUR

(COEFFICIENTS = 157238.9500 3480.2038 1753.6965)

LD = APR 21, 1979, 12.8980 HOURS GMT  
JULIAN DATE 43985.0370

AD = OCT 20, 1981, 0.8880 HOURS GMT  
JULIAN DATE 44897.5370

FLIGHT TIME = 912.5000 DAYS.

ELECTRIC PROPULSION SYSTEM PARAMETERS

ALPHA A (KG/KW)	ALPHA T (KG/KW)	TANKAGE FACTOR	STRUCTURE FACTOR	EFFICIENCY COEFFICIENTS
15.0000	15.0000	0.0350	0.0	B 0.63000 D (KM/SEC) 0.0 E 0.0

ELECTRIC PROPULSION SYSTEM MASS SUMMARY (KG)

INITIAL	POWER PLANT	PROPELLANT	TANKAGE	STRUCTURE	NET MASS
3268.5460	620.2500	1821.0737	63.7378	0.0	763.4795

ELECTRIC PROPULSION SYSTEM PERFORMANCE SUMMARY

P(I AU) (KW)	P(MSKP) (KW)	P(TARG) (KW)	THR(I AU) (N)	ACC(I AU) (M/SEC**2)	ISP (SEC)	EFFIC	CHAR DEG (DAYS)
20.3500	0.6500	20.3224	0.871551	2.666483D-04	3000.000	0.63000	1.00000000 30

EXTREME TRAJECTORY AND PERFORMANCE CONDITIONS

MAX DIST (AU)	MIN DIST (AU)	MAX POWER (KW)	MAX THRUST (N)	BURN TIME (DAYS)	DECRD TIME (DAYS)	TRAV ANG (DEG)
1.0169599	0.8296067	20.349999	0.37155141	714.95289	710.01587	948.26191

DEPARTURE AND ARRIVAL CONDITIONS

DEP DECL (DEG)	PARK INC (DEG)	DEP VINP (M/SEC)	C3 (KM**2/SEC**2)	ARR VINP (M/SEC)	C4 (KM**2/SEC**2)
-37.8537	36.0000	5099.62849	26.006211	0.0	0.0

## B. COMET RENDEZVOUS MISSION

The objective of this mission is to deliver maximum payload to the comet Tempel II, rendezvousing at perihelion of the comet's path in the 1988 apparition. For the case shown, the arrival date is fixed at September 16, 1988; the launch date and launch excess speed are optimized to yield maximum payload for the nominally 4-year class of solutions. The launch vehicle assumed is the Titan III E/Centaur. The electric propulsion system parameters are representative of projections of the SERT III spacecraft. Specifically, the reference power is 8.671 kw, the specific impulse is 2900 seconds, the efficiency is 0.63376 and the specific propulsion system mass (arrays plus power conditioning and thruster subsystem) is 30.285 kg/kw.

This example illustrates the use of the solar array degradation option. This option is invoked by setting the characteristic degradation time TPOWER to a value less than  $10^{10}$ . In this case, it is set to 7121 days which means that if the arrays were situated at 1 AU and oriented normal to the sun line for this amount of time, the power developed by the array would degrade to  $1/e$  of its initial power output. The input MPOW = 1 forces the arrays to be oriented normal to the sun line throughout the mission. Setting the triggers X30(2) and Y30(2) to 1 results in the optimal adjustment of the trajectory to accomodate the degradation. The complete set of inputs for this case follows and the resultant program output begins on the next page.

```
&MINPUT X1(2)=1.00,X2(2)=1.00,X3(2)=1.00,X4(2)=1.00,X5(2)=1.00
X6(2)=1.00,X11(2)=1.00,X13(2)=1.00,X15(2)=1.00,X7=1.00
Y1(2)=1.00,Y2(2)=1.00,Y3(2)=1.00,Y4(2)=1.00,Y5(2)=1.00,Y6(2)=1.00
Y13(2)=1.00,Y15(2)=1.00,ALPHAT=15.28500,MBOOST=15,MTMASS=3
MOPT2=3,MOPT3=43,MYEAR=1988,MONTH=9,MDAY=16,HOUR=17.2200
X12=2.843928504,BI=.6337600,DI=0.00,CTANK=.100,Y11=8.67100,3.00,1.0-3
TPOWER=7121.00,MPOW=1,X30(2)=1.00,Y30(2)=1.00
X1= 5.072998588224D 00, X2= 3.350183672126D 00, X3=-2.159808142389D 00
X4=-2.069314933312D 00, X5= 4.565247741305D 00, X6= 3.317322088503D-01
X11= 1.647979654151D-04,X13= 6.718039798493D 03,X15=-1.517625284470D 03
X30=-4.657406222646D-03 &END
```

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CASE 1

ITERATOR PARAMETERS

INDEPENDENT VARIABLES

NO.	INDEX	VALUE	STEP LIMIT	PERTURBATION	WEIGHT
1	1	5.0729985862240000 00	3.0000000000000000 00	1.0000000000000000-08	1.0000000000000000 00
2	2	3.3501836721260000 00	3.0000000000000000 00	1.0000000000000000-08	1.0000000000000000 00
3	3	-2.1598081423890000 00	3.0000000000000000 00	1.0000000000000000-08	1.0000000000000000 00
4	4	-2.0693149333120000 00	3.0000000000000000 00	1.0000000000000000-08	1.0000000000000000 00
5	5	4.5652477413050000 00	3.0000000000000000 00	1.0000000000000000-08	1.0000000000000000 00
6	6	3.3173226850309000-01	3.0000000000000000 00	1.0000000000000000-08	1.0000000000000000 00
7	11	1.6479796541510000-04	9.9999999999999999 00	1.0000000000000000-11	1.0000000000000000 00
8	13	6.7180397984529900 03	5.0000000000000000 00	9.9999999999999999 00	1.0000000000000000 00
9	15	-1.5176252844700000 03	8.0000000000000000 00	9.9999999999999999 00	1.0000000000000000 00
10	30	-4.6574062226459900-03	1.0000000000000000 01	9.9999999999999999 00	1.0000000000000000 00

DEPENDENT VARIABLES

NO.	INDEX	VALUE	TOLERANCE
1	1	0.0	9.9999999999999999 00
2	2	0.0	9.9999999999999999 00
3	3	0.0	9.9999999999999999 00
4	4	0.0	9.9999999999999999 00
5	5	0.0	9.9999999999999999 00
6	6	0.0	9.9999999999999999 00
7	11	8.6710000000000000 00	9.9999999999999999 00
8	13	0.0	9.9999999999999999 00
9	15	0.0	9.9999999999999999 00
10	30	0.0	9.9999999999999999 00

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----- NOMINAL TRAJECTORY 1 (TOTAL 1) ----- INHIBITOR IS 5.8208D-11 -----

INDEPENDENT PARAMETERS  
 1.PRIM1( 5.0729986D 00) 2.PRIM2( 3.3501837D 00) 3.PRIM3(-2.1598081D 00) 4.PDPT1(-2.0693149D 00) 5.PDPT2( 4.5652477D 00)  
 6.PDPT3( 3.3173221D-01) 11.ACCEL( 1.6479797D-04) 13.VINFI( 6.7180398D 03) 15.TIME1(-1.5176253D 03) 30.LDEGR(-4.6574062D-03)  
 DEPENDENT PARAMETERS  
 1.DELTA X(-8.88898D-02) 2.DELTA Y( 3.21013D-01) 3.DELTA Z(-1.56897D-03) 4.DELT XDI(-1.14063D-01) 5.DELT YDI( 2.32885D-01)  
 6.DELT ZDI( 5.61628D-03) 11. POWER ( 8.67100D 00) 13.T.VINFI(-4.41645D-02) 15.T.TIME1( 3.36196D-06) 30.T.DEGRD( 2.32504D-03)  
 THRUST SWITCHING TIMES (DAYS) 0.0 ON 1517.625 ON  
 ELECTRIC PROPULSION PARAMETERS  
 PROP TIME J  
 1517.6252844700 1.0915980627  
 MASS COMPONENT BREAKDOWN  
 PROPELLANT TANKAGE  
 443.0100468725 44.3010046873  
 EFFICIENCY 0.6337600000  
 PROPULSION 262.6012353301  
 INITIAL 2345.0574592971  
 PROP TIME RATIO 1.0000000000  
 STRUCTURE 0.0  
 PAYLOAD 1595.1451724072  
 AVE ACCEL 0.0001829860

----- NOMINAL TRAJECTORY 2 (TOTAL 6) ----- INHIBITOR IS 5.9605D-08 -----

INDEPENDENT PARAMETERS  
 1.PRIM1( 5.3132693D 00) 2.PRIM2( 3.3270277D 00) 3.PRIM3(-2.1717152D 00) 4.PDPT1(-2.0698180D 00) 5.PDPT2( 4.7839810D 00)  
 6.PDPT3( 3.1081327D-01) 11.ACCEL( 1.6287355D-04) 13.VINFI( 6.6775946D 03) 15.TIME1(-1.5192051D 03) 30.LDEGR(-2.8739127D-01)  
 DEPENDENT PARAMETERS  
 1.DELTA X( 2.52805D-01) 2.DELTA Y( 3.10551D-02) 3.DELTA Z(-3.77541D-02) 4.DELT XDI(-4.17647D-02) 5.DELT YDI(-1.35767D-03)  
 6.DELT ZDI( 4.36855D-02) 11. POWER ( 8.65952D 00) 13.T.VINFI(-7.25369D-02) 15.T.TIME1( 4.72439D-03) 30.T.DEGRD( 3.86791D-03)  
 THRUST SWITCHING TIMES (DAYS) 0.0 ON 1519.205 ON  
 ELECTRIC PROPULSION PARAMETERS  
 PROP TIME J  
 1519.2050826052 1.0241766936  
 MASS COMPONENT BREAKDOWN  
 PROPELLANT TANKAGE  
 429.072804939 42.9072804939  
 EFFICIENCY 0.6337600000  
 PROPULSION 262.2536886154  
 INITIAL 2369.6249929452  
 PROP TIME RATIO 1.0000000000  
 STRUCTURE 0.0  
 PAYLOAD 1635.3912188969  
 AVE ACCEL 0.0001799814

----- NOMINAL TRAJECTORY 3 (TOTAL 16) ----- INHIBITOR IS 3.9063D-03 -----

INDEPENDENT PARAMETERS  
 1.PRIM1( 5.3133875D 00) 2.PRIM2( 3.3268842D 00) 3.PRIM3(-2.1717072D 00) 4.PDPT1(-2.0695322D 00) 5.PDPT2( 4.7840736D 00)  
 6.PDPT3( 3.1878921D-01) 11.ACCEL( 1.6099008D-04) 13.VINFI( 6.7247596D 03) 15.TIME1(-1.5190491D 03) 30.LDEGR(-3.1763748D-03)  
 DEPENDENT PARAMETERS  
 1.DELTA X(-7.41178D-04) 2.DELTA Y( 8.36556D-02) 3.DELTA Z(-1.09468D-02) 4.DELT XDI(-5.15364D-02) 5.DELT YDI( 4.91521D-02)  
 6.DELT ZDI( 8.26291D-03) 11. POWER ( 8.45577D 00) 13.T.VINFI(-2.37939D-02) 15.T.TIME1( 1.66400D-03) 30.T.DEGRD( 1.44326D-03)  
 THRUST SWITCHING TIMES (DAYS) 0.0 ON 1206.867 OFF 1375.891 ON 1519.048 ON  
 ELECTRIC PROPULSION PARAMETERS  
 PROP TIME J  
 1350.0244116041 0.8691215491  
 MASS COMPONENT BREAKDOWN  
 PROPELLANT TANKAGE  
 373.4807477299 37.3480747730  
 EFFICIENCY 0.6337600000  
 PROPULSION 256.0829096522  
 INITIAL 2340.9387961429  
 PROP TIME RATIO 0.8887305043  
 STRUCTURE 0.0  
 PAYLOAD 1074.0270639878  
 AVE ACCEL 0.0001756068

NOMINAL TRAJECTORY 4 (TOTAL 19) INHIBITOR IS 1.5259D-05			
INDEPENDENT PARAMETERS			
1.PRIM1( 5.3132020D 00)	2.PRIM2( 3.3269287D 00)	3.PRIM3( -2.1715769D 00)	4.POOT1( -2.0689020D 00)
6.POOT3( 3.1889725D-01)	11.ACCEL( 1.6258740D-04)	13.VINFI( 6.7131835D 03)	15.TIME1( -1.5191023D 03)
DEPENDENT PARAMETERS			
1.DELTA X( -5.60128D-03)	2.DELTA Y( -1.72518D-02)	3.DELTA Z( 2.42312D-04)	4.DELT XO( -1.73773D-03)
6.DELT ZO( 8.54559D-03)	11. POWER ( 8.56555D 00)	13.T.VINFI( -2.85065D-02)	15.T.TIME1( 4.81076D-04)
THRUST SWITCHING TIMES (DAYS)			
0.0	0.0	1236.139 OFF	1372.865 ON
ELECTRIC PROPU-SION PARAMETERS			
PROP TIME	1382.3770859819	0.8952147629	0.9099960737
EFFICIENCY	0.6337600000	MASS COMPONENT BREAKDOWN	0.0001776305
PROPULSION	259.4076771027	PROPELLANT	PAYLOAD
INITIAL	2348.0346249507	TANKAGE	1669.6815818760
STRUCTURE			
0.0			

  

NOMINAL TRAJECTORY 5 (TOTAL 22) INHIBITOR IS 5.9605D-08			
INDEPENDENT PARAMETERS			
1.PRIM1( 5.2191362D 00)	2.PRIM2( 3.2734061D 00)	3.PRIM3( -2.1653385D 00)	4.POOT1( -2.0287369D 00)
6.POOT3( 3.0652065D-01)	11.ACCEL( 1.6373773D-04)	13.VINFI( 6.7145376D 03)	15.TIME1( -1.5190635D 03)
DEPENDENT PARAMETERS			
1.DELTA X( 1.33510D-03)	2.DELTA Y( 2.14569D-03)	3.DELTA Z( -2.39479D-03)	4.DELT XO( -3.35654D-03)
6.DELT ZO( 3.88323D-03)	11. POWER ( 8.62268D 00)	13.T.VINFI( -1.21597D-02)	15.T.TIME1( 4.41532D-04)
THRUST SWITCHING TIMES (DAYS)			
0.0	0.0	1232.409 OFF	1374.451 ON
ELECTRIC PROPU-SION PARAMETERS			
PROP TIME	1377.0217396572	0.9071750874	0.9064938549
EFFICIENCY	0.6337600000	MASS COMPONENT BREAKDOWN	0.0001789778
PROPULSION	261.1438406008	PROPELLANT	PAYLOAD
INITIAL	2347.1431552637	TANKAGE	1665.0255274835
STRUCTURE			
0.0			

  

NOMINAL TRAJECTORY 6 (TOTAL 27) INHIBITOR IS 7.8506D-09			
INDEPENDENT PARAMETERS			
1.PRIM1( 5.1599153D 00)	2.PRIM2( 3.2549972D 00)	3.PRIM3( -2.1596535D 00)	4.POOT1( -2.0104620D 00)
6.POOT3( 2.8968390D-01)	11.ACCEL( 1.6440323D-04)	13.VINFI( 6.7141174D 03)	15.TIME1( -1.5189516D 03)
DEPENDENT PARAMETERS			
1.DELTA X( 7.45271D-04)	2.DELTA Y( -6.39267D-04)	3.DELTA Z( -1.51192D-03)	4.DELT XO( -7.33083D-04)
6.DELT ZO( 1.70128D-03)	11. POWER ( 8.65910D 00)	13.T.VINFI( -3.47048D-03)	15.T.TIME1( -1.05360D-05)
THRUST SWITCHING TIMES (DAYS)			
0.0	0.0	1237.403 OFF	1369.671 ON
ELECTRIC PROPU-SION PARAMETERS			
PROP TIME	1386.6839452631	0.9231469282	0.9129217404
EFFICIENCY	0.6337600000	MASS COMPONENT BREAKDOWN	0.0001799027
PROPULSION	262.2408639344	PROPELLANT	PAYLOAD
INITIAL	2347.4620903736	TANKAGE	1659.4481270183
STRUCTURE			
0.0			

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----- NOMINAL TRAJECTORY 7 (TOTAL 32) ----- INHIBITOR IS 1.4901D-08 -----

INDEPENDENT PARAMETERS

1.PRIMI( 5.1336404D 00) 2.PRIMI2( 3.2629313D 00) 3.PRIMI3( 2.1557714D 00) 4.PDOT1( -2.0141728D 00) 5.PDOT2( 4.6048405D 00)  
6.PDOT3( 2.8387868D -01) 11.ACCEL( 1.6460417D -04) 13.VINFI( 6.7137432D 03) 15.TIME1( -1.5187710D 03) 30.LDEGR( -5.1412997D -03)

DEPENDENT PARAMETERS

1.DELTA X( 2.35927D -04) 2.DELTA Y( -1.07608D -04) 3.DELTA Z( -5.52100D -04) 4.DELT XD( -3.29142D -04) 5.DELT YD( -3.09067D -03)  
6.DELT ZD( 7.41430D -04) 11. POWER ( 8.67053D 00) 13.T.VINFI( -6.54911D -04) 15.T.TIME1( -2.23981D -04) 30.T.DEGRD( -4.99774D -04)

THRUST SWITCHING TIMES (DAYS) 0.0 ON 1239.035 OFF 1368.048 ON 1518.771 ON

ELECTRIC PROPULSION PARAMETERS

POWER 8.6705313436 EFFICIENCY 0.6337600000 PROP TIME 1389.7385967565 J PROP TIME RATIO 0.9150547169 AVE ACCEL 0.0001801835  
MASS COMPONENT BREAKDOWN

INITIAL 2347.6914743591 PROPULSION 262.5870417409 PROPELLANT 388.4296679449 TANKAGE 38.8429667945 STRUCTURE 0.0 PAYLOAD 1657.8317978787

----- NOMINAL TRAJECTORY 8 (TOTAL 36) ----- INHIBITOR IS 3.7253D-09 -----

INDEPENDENT PARAMETERS

1.PRIMI( 5.1088483D 00) 2.PRIMI2( 3.2963260D 00) 3.PRIMI3( 2.1550970D 00) 4.PDOT1( -2.0358208D 00) 5.PDOT2( 4.5872536D 00)  
6.PDOT3( 2.9845884D -01) 11.ACCEL( 1.6467645D -04) 13.VINFI( 6.7147767D 03) 15.TIME1( -1.5184032D 03) 30.LDEGR( -4.8228050D -03)

DEPENDENT PARAMETERS

1.DELTA X( 2.39729D -04) 2.DELTA Y( -1.27285D -04) 3.DELTA Z( -8.13075D -05) 4.DELT XD( -1.09389D -04) 5.DELT YD( -1.96172D -03)  
6.DELT ZD( 4.01517D -04) 11. POWER ( 8.67200D 00) 13.T.VINFI( -1.33191D -04) 15.T.TIME1( -1.48701D -04) 30.T.DEGRD( -1.80187D -04)

THRUST SWITCHING TIMES (DAYS) 0.0 ON 1238.824 OFF 1363.853 ON 1518.433 ON

ELECTRIC PROPULSION PARAMETERS

POWER 8.671973228 EFFICIENCY 0.6337600000 PROP TIME 1393.3738931869 J PROP TIME RATIO 0.9176574035 AVE ACCEL 0.0001803267  
MASS COMPONENT BREAKDOWN

INITIAL 2347.0578738041 PROPULSION 262.6314389198 PROPELLANT 389.7150553725 TANKAGE 38.9715055373 STRUCTURE 0.0 PAYLOAD 1655.7398739742

----- NOMINAL TRAJECTORY 9 (TOTAL 39) ----- INHIBITOR IS 1.1642D-10 -----

INDEPENDENT PARAMETERS

1.PRIMI( 5.0760147D 00) 2.PRIMI2( 3.3463430D 00) 3.PRIMI3( -2.1582755D 00) 4.PDOT1( -2.0671646D 00) 5.PDOT2( 4.5669170D 00)  
6.PDOT3( 3.2898985D -01) 11.ACCEL( 1.6477406D -04) 13.VINFI( 6.7174628D 03) 15.TIME1( -1.5178833D 03) 30.LDEGR( -4.6613107D -03)

DEPENDENT PARAMETERS

1.DELTA X( 4.84058D -04) 2.DELTA Y( -9.14775D -04) 3.DELTA Z( -1.93914D -05) 4.DELT XD( 2.63154D -04) 5.DELT YD( -7.39846D -04)  
6.DELT ZD( 1.52396D -04) 11. POWER ( 8.67105D 00) 13.T.VINFI( -1.49676D -04) 15.T.TIME1( 9.64158D -06) 30.T.DEGRD( -3.70422D -06)

THRUST SWITCHING TIMES (DAYS) 0.0 ON 1237.601 OFF 1356.688 ON 1517.883 ON

ELECTRIC PROPULSION PARAMETERS

POWER 8.6710499330 EFFICIENCY 0.6337600000 PROP TIME 1398.7961204684 J PROP TIME RATIO 0.9215439260 AVE ACCEL 0.0001805308  
MASS COMPONENT BREAKDOWN

INITIAL 2345.4111595641 PROPULSION 262.602747223 PROPELLANT 391.5490838753 TANKAGE 39.1549083875 STRUCTURE 0.0 PAYLOAD 1652.1044200790

THIS CASE IS CONVERGED.

40 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND 9 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

TIME	SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	NODE	ARG POS	RMAG	TRAVEL
R1	R2	R3	V1	V2	V3	MASS RATIO	THRUST ACC
L1	L2	L3	L4	L5	L6	L7	HAM
LG	LC	LPHI	CONE	CLOCK	HMAG	POWER FNCT	SWITCH FNCT
PSI	THETA	PHI	LATITUDE	LONGITUDE	FLT PTH ANGLE	VMAG	PROP TIME
S	LS	DENSITY	DPOWR	DPOWD	DEGRAD	CHI	CHI REF

## EARTH

## START OF TRAJECTORY, THRUST ON

0.0	1.880516470 00	4.599686060-01	3.610570230 00	1.192465440 02	1.900000000 02	1.015998430 00	0.0
4.063849450-01	-8.864845150-01	0.0	1.033722930 00	6.020455560-01	-7.847315200-02	1.000000000 00	2.722821470-02
5.073909600 00	3.348838750 00	-2.158814920 00	-2.068522770 00	4.565730810 00	3.310356990-01	1.000000000 00	-1.373006600-02
0.0	0.0	0.0	7.631060770 01	6.672519420 01	1.211764200 00	9.798629180-01	5.238358410 00
-1.554899530 01	9.409532320 01	9.393742880 01	0.0	-6.075345590 01	-9.682721730-01	1.198640130 00	0.0
0.0	-4.655926720-03	9.687549330-01	-1.245431430 00	6.530838360-01	1.000000000 00	0.0	0.0

## SWITCH THRUST OFF

1.236831020 03	2.670456720 00	4.906303780-01	1.088257370 01	1.256320400 02	6.676745400 01	2.736706240 00	2.529460510 02
-2.636112110 00	-5.612945280-01	4.747843590-01	3.965664350-01	-4.860203160-01	-1.201154030-02	8.713523710-01	6.082873110-03
3.753070330-01	-1.410862880 00	7.031355380-01	1.929233230-01	1.931258400-01	-9.358536950-01	1.770179140 00	-1.373012670-02
-1.952116370 01	-1.884670690-01	0.0	8.092104450 01	1.301452530 02	1.823959140 00	1.907430540-01	-1.270511470-14
2.146249340 01	8.810606830 01	8.823744160 01	9.990652720 00	-1.679797350 02	-2.935071840 01	5.969450060-01	1.236831020 03
1.977884870 02	-2.276258480-04	1.335191740-01	-1.278136900-01	1.309881140 00	9.726068080-01	9.000000000 01	9.000000000-01

## SWITCH THRUST ON

1.357152550 03	2.670456720 00	4.906303780-01	1.088257370 01	1.256320400 02	6.676745400 01	2.736706240 00	2.529460510 02
-1.506145910 00	-1.362417890 00	3.879444520-01	7.106320370-01	-2.855118230-01	-7.305360060-02	8.713523710-01	1.004256650-02
7.141742660-01	-8.623381710-01	-1.171796060 00	1.305279230-01	3.725147820-01	-8.547453840-01	1.770179140 00	-1.373012670-02
-1.952116370 01	-1.884670690-01	0.0	7.293758730 01	5.706362440 01	1.423959140 00	3.149087240-01	-8.239936510-17
-4.449965370 01	9.855055800 01	9.608756600 01	1.081428230 01	-1.378683790 02	-2.555124480 01	7.999490370-01	1.236831020 03
1.977884870 02	-2.276258480-04	2.339094340-01	-2.649232770-01	1.170898320 00	9.726068080-01	0.0	0.0

## TEMPEL II(1988)

## END OF TRAJECTORY, THRUST ON

1.517856370 03	3.036730040 00	5.444316480-01	1.243166500 01	1.191191310 02	1.910410780 02	1.383439100 00	3.708293540 02
8.867712800-01	-1.060322840 00	-5.703626660-02	7.862621490-01	6.695707070-01	-2.232464320-01	8.331846790-01	2.022630780-02
6.323711340-01	9.398167120-01	-2.184943770 00	-4.080751530-01	8.725228400-01	5.181773140-01	1.884739160 00	-1.373014410-02
-2.052469830 01	-2.613432850-01	0.0	7.957856500 01	2.022545020 01	1.951723080 00	6.064626290-01	8.164861830-01
-5.113642560 01	9.837360070 01	9.524279680 01	-2.362855150 00	-5.009352010 01	2.633763800-04	1.056585100 00	1.397534440 03
2.597744360 02	2.211485150-08	5.224930740-01	-5.798674750-01	9.030641530-01	9.641773290-01	0.0	0.0

## CASE 1

## ITERATOR SUMMARY

## INDEPENDENT PARAMETERS

```

1.PRIM1( 5.0739096D 00) 2.PRIM2( 3.3488387D 00) 3.PRIM3(-2.1589149D 00) 4.POOT1(-2.0685228D 00) 5.POOT2( 4.5657308D 00)
6.POOT3( 3.3103570D-01) 7.LMASS( 1.0000000D 00) 8.LTAU( 0.0 ) 9. ( 0.0 ) 10.DECLN( 0.0 )
11.ACCEL( 1.6478510D-04) 12.V JET( 2.8439285D 04) 13.VINF1( 6.7177410D 03) 14.VINF2( 0.0 ) 15.TIME1(-1.5178564D 03)
16.TIME2( 0.0 ) 17.IPARK( 0.0 ) 18.VE-JI( 0.0 ) 19.VELJ2( 0.0 ) 20.VELOJ3( 0.0 )
21.THET1( 0.0 ) 22.THET2( 0.0 ) 23.THET3( 0.0 ) 24.THET4( 0.0 ) 25.THET5( 0.0 )
26.THET6( 0.0 ) 27.THET7( 0.0 ) 28.THET8( 0.0 ) 29.THET9( 0.0 ) 30.LDEGR(-4.6559267D-03)
31.PHI1( 0.0 ) 32.PHI2( 0.0 ) 33.PHI3( 0.0 ) 34.PHI4( 0.0 ) 35.PHI5( 0.0 )
36.PHI6( 0.0 ) 37.PHI7( 0.0 ) 38.PHI8( 0.0 ) 39.PHI9( 0.0 ) 40.PHI10( 0.0 )
41.PRI-A( 0.0 ) 42.PR2-A( 0.0 ) 43.PR3-A( 0.0 ) 44.PDI-A( 0.0 ) 45.PD2-A( 0.0 )
46.PD3-A( 0.0 ) 47.VINFA( 0.0 ) 48.TTWEA( 0.0 ) 49.KSAMP( 0.0 ) 50.KOROP( 0.0 )
51.PRI-B( 0.0 ) 52.PR2-B( 0.0 ) 53.PR3-B( 0.0 ) 54.PDI-B( 0.0 ) 55.PD2-B( 0.0 )
56.PD3-B( 0.0 ) 57.VINF8( 0.0 ) 58.TTWE3( 0.0 ) 59.KSAMP( 0.0 ) 60.KOROP( 0.0 )
61.PRI-C( 0.0 ) 62.PR2-C( 0.0 ) 63.PR3-C( 0.0 ) 64.PDI-C( 0.0 ) 65.PD2-C( 0.0 )
66.PD3-C( 0.0 ) 67.VINF1( 0.0 ) 68.TIME1( 0.0 ) 69.KSAMP( 0.0 ) 70.KOROP( 0.0 )

```

## DEPENDENT PARAMETERS

```

1.DELTA X( 4.65245D-06) 2.DELTA Y(-8.98292D-06) 3.DELTA Z(-6.49573D-07) 4.DELT XD( 2.39851D-06) 5.DELT YD(-6.47139D-06)
6.DELT ZD( 1.01292D-06) 7. ( 0.0 ) 8. ( 0.0 ) 9. ( 0.0 ) 10. ( 0.0 )
11.POWER( 8.67100D 00) 12. ( 0.0 ) 13.T.VINF1(-1.06427D-06) 14. ( 0.0 ) 15.T.TIME1( 7.73449D-08)
16. ( 0.0 ) 17. ( 0.0 ) 18. ( 0.0 ) 19. ( 0.0 ) 20. ( 0.0 )
21. ( 0.0 ) 22. ( 0.0 ) 23. ( 0.0 ) 24. ( 0.0 ) 25. ( 0.0 )
26. ( 0.0 ) 27. ( 0.0 ) 28. ( 0.0 ) 29. ( 0.0 ) 30.T.DEGRD( 2.21149D-08)
31. ( 0.0 ) 32. ( 0.0 ) 33. ( 0.0 ) 34. ( 0.0 ) 35. ( 0.0 )
36. ( 0.0 ) 37. ( 0.0 ) 38. ( 0.0 ) 39. ( 0.0 ) 40. ( 0.0 )
41. ( 0.0 ) 42. ( 0.0 ) 43. ( 0.0 ) 44. ( 0.0 ) 45. ( 0.0 )
46. ( 0.0 ) 47. ( 0.0 ) 48. ( 0.0 ) 49. ( 0.0 ) 50. ( 0.0 )
51. ( 0.0 ) 52. ( 0.0 ) 53. ( 0.0 ) 54. ( 0.0 ) 55. ( 0.0 )
56. ( 0.0 ) 57. ( 0.0 ) 58. ( 0.0 ) 59. ( 0.0 ) 60. ( 0.0 )
61. ( 0.0 ) 62. ( 0.0 ) 63. ( 0.0 ) 64. ( 0.0 ) 65. ( 0.0 )
66. ( 0.0 ) 67. ( 0.0 ) 68. ( 0.0 ) 69. ( 0.0 ) 70. ( 0.0 )

```

THRUST SWITCHING TIMES (DAYS)

ON 1236.831 OFF 1357.153 ON 1517.856 ON

## ELECTRIC PROPULSION PARAMETERS

```

POWER 8.6710000072 EFFICIENCY 0.6337600000 PROP TIME 1397.5344446940 PROP TIME RATIO 0.9207290424 AVE ACCEL 0.0001805291

```

## MASS COMPONENT BREAKDOWN

```

INITIAL 2345.2405989059 PROPULSION 262.6012352180 PROPELLANT 391.2220623059 TANKAGE 39.1222062306 STRUCTURE 0.0 PAYLOAD 1652.2950951515

```

SWITCH-COUNT HISTORY 2.2.4.4.4.4.4.4.4/

204 THRUST COMPUTE STEPS. 7 COAST COMPUTE STEPS

CASE 1 EXTREMUM POINTS OF SELECTED FUNCTIONS

I	TIME	ECLIPTIC LONGITUDE	SOLAR DISTANCE	COMMUNICATION ANGLE	SWITCH FUNCTION	PSI	THRUST ANGLES THETA	PHI	INPUT POWER	ARRAY ANGLE
0	0.0	0.0	1.016	86.1	ON	-15.9	94.1	93.9	8.5	ON
4	1.834	2.1	1.016	87.7	5.25D 00	-15.8	93.4	93.3	8.5	MAX
4	2.644	3.1	1.016	88.4	5.25D 00	-15.7	93.1	93.0	8.5	0.0
4	13.958	16.2	1.024	98.7	MAX	-14.4	98.8	98.9	8.4	0.0
5	83.425	80.3	1.364	MAX 166.0	4.15D 00	-0.4	69.7	69.7	5.5	0.0
4	152.250	114.2	1.867	115.4	3.83D 00	19.1	62.8	64.5	3.3	0.0
5	173.169	121.2	2.016	101.0	MIN	36.5	62.0	64.8	2.9	0.0
4	226.549	135.4	2.372	67.2	3.94D 00	51.5	63.0	73.6	1.4	0.0
5	339.725	155.6	2.932	0.9	4.55D 00	53.6	63.7	74.8	1.3	0.0
7	367.048	159.4	3.115	16.9	MAX	61.0	68.7	79.9	1.0	0.0
7	539.712	178.8	3.679	171.8	MIN	61.1	68.9	80.0	0.9	0.0
5	546.123	179.4	3.694	MAX 178.3	2.71	61.3	69.2	80.2	0.9	0.0
4	555.805	180.3	3.714	167.8	MAX	62.7	74.3	82.9	0.8	0.0
4	714.156	194.5	3.913	24.1	4.85D 00	62.6	74.5	83.0	0.8	0.0
5	748.378	197.5	3.922	2.8	MAX	59.7	78.9	84.4	0.9	0.0
5	757.403	198.3	3.922	2.8	MAX	47.6	83.6	85.7	1.2	0.0
5	759.248	198.4	3.922	6.6	4.55D 00	43.7	84.5	86.1	1.3	0.0
5	946.761	215.3	3.742	7.8	4.51D 00	43.7	84.5	86.1	1.3	0.0
5	953.421	216.0	3.729	MAX 172.0	2.76	43.7	84.5	86.1	1.3	0.0
4	1131.643	236.1	3.207	MIN 168.6	3.17D 00	43.7	84.5	86.1	1.3	0.0
4	1157.452	239.7	3.103	17.6	MAX	43.7	84.5	86.1	1.3	0.0
4	1236.831	252.8	2.737	6.7	8.55D-01	43.7	84.5	86.1	1.3	0.0
5	1296.317	265.5	2.420	50.4	OFF -1.27D-14	21.5	88.1	88.2	0.0	90.0
7	1357.153	282.9	2.068	89.3	MIN -2.97D-01	*****	88.1	88.2	0.0	90.0
5	1394.950	297.1	1.845	134.8	ON -8.24D-17	44.5	98.6	96.1	2.7	0.0
6	1432.834	315.0	1.636	0.97	3.37D-01	-54.7	102.7	97.3	3.3	0.0
5	1441.845	319.9	1.591	133.2	6.55D-01	-58.8	105.2	97.8	4.0	0.0
4	1444.313	321.3	1.579	125.7	7.17D-01	-59.1	105.4	97.8	4.2	0.0
4	1446.468	322.6	1.569	0.77	7.33D-01	-59.1	105.4	97.8	4.3	0.0
4	1489.227	350.0	1.417	122.1	7.45D-01	MIN -59.1	105.4	97.8	4.3	0.0
4	1517.072	370.1	1.383	97.8	MAX 8.79D-01	-56.3	102.6	96.9	5.1	0.0
3	1517.855	370.7	1.383	89.4	8.20D-01	-51.3	98.5	95.3	5.3	0.0
4	1517.856	370.7	1.383	89.2	8.15D-01	-51.1	98.4	95.2	5.3	0.0
				89.2	ON 8.15D-01	-51.1	98.4	95.2	5.3	ON 0.0

MISSION SCHEDULE

PLANET	S/C	X	Y	Z	DEPART	EARTH	XDOT	YDOT	ZDOT	RADIUS	LAT.	LONG.
JULY 21, 1984		2.08670503D-01	G.M.I.									
		2442301.321D-00	JULIAN DATE									
PLANET	4.9638494D-01	-8.8648451D-01	0.0		8.5633575D-01	4.8496863D-01	0.0			1.0159984D 00	0.0	-60.753
S/C	4.9638494D-01	-8.8648451D-01	0.0		1.0337229D 00	6.0294556D-01	-7.5473152D-02			1.0159984D 00	0.0	-60.753

PLANET	S/C	X	Y	Z	DEPART	EARTH	XDOT	YDOT	ZDOT	RADIUS	LAT.	LONG.
SEPTEMBER 16, 1988		1.72200000D-01	G.M.I.									
		2447321.219D-00	JULIAN DATE									
PLANET	8.8676663D-01	-1.0603139D 00	-5.7035617D-02		7.8625973D-01	6.6957718D-01	-2.232474D-01			1.3834282D 00	-2.363	-50.093
S/C	8.8677128D-01	-1.0603228D 00	-5.7036267D-02		7.8625215D-01	6.6957071D-01	-2.2324643D-01			1.3834381D 00	-2.363	-50.094
TWO-BODY TRANSFER ANGLE BETWEEN EARTH AND TEMPEL II(1986) IS 10.9158 DEGREES.												

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# CASE 1 (CONVERGED)

## PERFORMANCE SUMMARY

EARTH TO TEMPEL III(1988) WITH FIXED ARRIVAL EXCESS SPEED

ARRIVAL AT TEMPEL III(1988) PERIHELION

LAUNCH VEHICLE IS TITAN III E/CENTAUR

(COEFFICIENTS = 167238.9500 3480.2038 1753.6965)

LD = JUL 21. 1984. 20.6671 HOURS GMT  
JULIAN DATE 45903.3611

AD = SEP 16. 1988. 17.2200 HOURS GMT  
JULIAN DATE 47421.2175

FLIGHT TIME = 1517.8564 DAYS.

### ELECTRIC PROPULSION SYSTEM PARAMETERS

ALPHA A (KG/KW)	ALPHA T (KG/KW)	TANKAGE FACTOR	STRUCTURE FACTOR	B	D (KV/SEC)	E
15.0000	15.2850	0.1000	0.0	0.63376	0.0	0.0

### ELECTRIC PROPULSION SYSTEM MASS SUMMARY (KG)

INITIAL	POWER PLANT	PROPELLANT	TANKAGE	STRUCTURE	NET MASS
2345.2406	262.6012	391.2221	39.1222	0.0	1652.2951

### ELECTRIC PROPULSION SYSTEM PERFORMANCE SUMMARY

P(1 AU) (KW)	P(TARG) (KW)	T4R(1 AU) (N)	ACC(1 AU) (M/SEC**2)	ISP (SEC)	EFFIC	CHAR DEG (DAYS)
8.6710	5.2586	0.386461	1.647851D-04	2900.000	0.63376	7.1210000D 03
						CONSTRAINED MAX

### EXTREME TRAJECTORY AND PERFORMANCE CONDITIONS

MAX DIST (AU)	MIN DIST (AU)	MAX POWER (KW)	MAX THRUST (N)	BURN TIME (DAYS)	DEGRD TIME (DAYS)	TRAV ANG (DEG)
3.9221510	1.0155371	8.498784	0.37878516	1397.5344	259.77444	370.82935

### DEPARTURE AND ARRIVAL CONDITIONS

DEP DECL (DEG)	PARK INC (DEG)	DEP VINP (M/SEC)	C3 (KM**2/SEC**2)	ARR VINP (M/SEC)	C4 (KM**2/SEC**2)
-5.7634	28.5000	6717.74104	45.128045	0.20776	0.000000

### C. MULTIPLE BALLISTIC SWINGBY MISSION

This computer run demonstrates how the program may be effectively used in the investigation of all-ballistic missions (with electric propulsion absent).

In general, trajectories are forced to be all-ballistic by setting the propulsion-time adjoint variable  $X_8$  to a "large" negative number ( $X_8 = -1.D3$ ) with respect to the mass ratio adjoint variable  $X_7 = 1.D0$ . These settings (together with the reference thrust acceleration  $X_{11} = 1.D-4$ , jet exhaust speed  $X_{12} = 1.D0$ , and non-zero primer vector components  $X_2 = .1D0$  at the launch planet and  $X_{42} = .1D0$  at the first intermediate-target) guarantee that the electric propulsion thrust switch-function will be maintained negative, yielding ballistic flight at all times. The electric propulsion specific masses  $ALPHAA$  and  $ALPHAT$  are also set to zero, so that the net spacecraft mass equals the launch vehicle payload.

The particular ballistic mission simulation demonstrated here involves a March 6, 1985 launch of a 1,635 kg payload by an Atlas/Centaur launch vehicle (using the launch vehicle selection default-value of  $MBOOST = 0$ ; actually, changing  $MBOOST$  alters the payload mass computation but not the  $C_3$  or the trajectory).

The primary target is the Earth, specified by  $MOPT3 = 3$ , and there is one intermediate target, the comet Giacobini-Zinner, specified by  $MOPTX = 41$ . The launch occurs fifteen days before ( $X_{15} = -15.D0$ ) the reference date ( $MYEAR = 1985$ ,  $MONTH = 3$ ,  $MDAY = 21$ ), and the spacecraft passes Giacobini-Zinner 174.22 days ( $X_{48}$ ) after the reference date and arrives back at Earth 353 days ( $X_{16}$ ) after the reference date.

Ten days after passing Giacobini-Zinner a deep-space burn (of 188.9 m/sec) makes possible the re-targeting to Earth. This is accomplished by inputting  $TDV = 1.00010D5$  together with  $X_{64}(2)$ ,  $X_{65}(2)$ , and  $X_{66}(2) = 1.D0$ .

The deep space burn velocity-increment (X64, X65, X66) initial guess is the zero vector, by default. The deep-space burn could just have well occurred before arriving at Giacobini-Zinner (e.g., TDV = 2.00005D5). The iteration sequence consists of a 6x6 hunt, with the independent variables being the initial heliocentric velocity at Earth (X18, X19, X20) and the deep-space burn velocity increment (X64, X65, X66), and the dependent variables being the position targeting at Giacobini-Zinner (Y41, Y42, Y43) and at Earth (Y1, Y2, Y3). The setting MAXHAM = 0 is made to avoid an unwarranted BAD HAMILTONIAN warning message due to the presence of the deep-space burn.

The detailed printout of the iteration sequence is omitted by setting NPRINT = 3 (compared to the default value NPRINT = 7), and three extra lines are added to each print-block by setting MPRINT = 2.

Finally, the multiple ballistic swingby option is invoked by means of MOPT4 = -3, 42, which directs the spacecraft to swingby the primary target (Earth) in such a manner as to re-target to Earth (MOPT4(1) = -3), and then, at the second Earth passage, to again swingby in such a manner as to target to the comet Borrelly (MOPT4(2) = 42). Furthermore, the first Earth swingby is specified as unpowered (MSWING(1) = -1) having T2(1) = 480 days as the initial guess of the Earth-to-Earth transfer time, and the second Earth swingby is specified to be powered (MSWING(2) = -5) with a specified transfer time from Earth to Borrelly (T2(2) = 127 days) and using the input Earth-departure heliocentric velocity initial-guess XSWING(1,2) = .62D0, .91D0, 0.D0. Both swingby iterations converged, and the powered-swingby incremental speed turned out to be -13.7 m/sec, the minus sign denoting a braking burn. The default value of TGO = -1.D0 resulted in the printout of several pages describing the trajectory segments following the time of primary target passage.

It should be noted that the trajectory simulation would have terminated at the primary target (first Earth encounter) if MOPT4(1) were zero, and would have terminated at the second Earth encounter had MOPT4(2) been zero. The

mission, as simulated, thus consists initially of a comet-flyby, followed by a second comet-flyby making use of a double Earth-swingby to reach the second comet.

The inputs for this computer run are listed below, and the resulting program output is displayed on the following pages.

```
&MINPUT X7=1.D0,X2=.1D0,X42=.1D0,X8=-1.D3,ALPHA=0.D0,ALPHAT=0.D0  
X64(2)=1.D0,X65(2)=1.D0,X66(2)=1.D0,X18(2)=1.D0,X19(2)=1.D0,X20(2)=1.D0  
Y1(2)=1.D0,Y2(2)=1.D0,Y3(2)=1.D0,Y41(2)=1.D0,Y42(2)=1.D0,Y43(2)=1.D0  
MYEAR=1985,MONTH=3,MDAY=21,MOPT2=3,MOPT3=3,MOPTX=41,X11=1.D-4,X12=1.D0  
TDV=1.00010D5,X15=-15.D0,X16=353.D0,X48=174.22D0  
X18=-8.3276D-2,X19=-1.0034D0,X20=-2.0143D-3  
T2=480.D0,127.D0,XSWING(1,2)=.62D0,.91D0,0.D0  
MOPT4=-3,42,MSWING=-1,-5,MPRINT=2,MAXHAM=0,NPRINT=3 &END
```

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# CASE 1

## ITERATOR PARAMETERS

		INDEPENDENT VARIABLES			
NO.	INDEX	VALUE	STEP LIMIT	PERTURBATION	WEIGHT
1	18	-8.327600000000000000D-02	1.000000000000000000D 03	9.999999999999999999D-05	1.000000000000000000D 00
2	19	-1.003400000000000000D 00	1.000000000000000000D 03	9.999999999999999999D-05	1.000000000000000000D 00
3	20	-2.014300000000000000D-03	1.000000000000000000D 00	9.999999999999999999D-05	1.000000000000000000D 00
4	64	0.0	3.000000000000000000D 03	1.000000000000000000D-08	1.000000000000000000D 00
5	65	0.0	3.000000000000000000D 00	1.000000000000000000D-08	1.000000000000000000D 00
6	66	0.0	3.000000000000000000D 03	1.000000000000000000D-08	1.000000000000000000D 00

## DEPENDENT VARIABLES

NO.	INDEX	VALUE	TOLERANCE
1	1	0.0	9.999999999999999999D-05
2	2	0.0	9.999999999999999999D-05
3	3	0.0	9.999999999999999999D-05
4	41	0.0	9.999999999999999999D-05
5	42	0.0	9.999999999999999999D-05
6	43	0.0	9.999999999999999999D-05

THIS CASE IS CONVERGED.

8 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND 3 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.



## CASE 1

## SWITCH POINT SUMMARY

PAGE 1

TIME	SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	MODE	ARG POS	RMAG	TRAVEL
R1	R3	R3	V1	V2	V3	MASS RATIO	THRUST ACC
L1	L3	L3	L4	L5	L6	L7	HAM
LG	LPHI	CONC	CLCK	HMAG	FLT PTH ANGLE	POWER FNCT	SWITCH FNCT
PSI	THETA	PHI	LATITUDE	LONGITUDE	V2 REL	VMAG	PROP TIME
R2 REL	R3 REL	R3 REL	V1 REL	V2 REL	ANG(V,R)	RMAG REL	VMAG REL
S/C NUC MAG	S/C TOT MAG	GEO NUC MAG	3RD TOT MAG	ANG(V,R)	ANG(V,XY)	RMAG ECL	VMAG ECL
R1 REL ECL	R2 REL ECL	R3 REL ECL	V1 REL ECL	V2 REL ECL	V3 REL ECL	RMAG ECL	VMAG ECL

## EARTH

## START OF TRAJECTORY, THRUST OFF

0.0	9.966431370-01	9.877358070-02	1.012293300-01	3.458709420-02	1.800000000-02	9.923389820-01	0.0
-9.42221040-01	2.422123450-01	0.0	-1.481254690-01	-9.951537530-01	-1.768923210-03	1.000000000-00	1.703031860-02
0.0	1.000000000-01	0.0	0.0	0.0	0.0	1.000000000-00	-2.479404690-02
0.0	0.0	0.0	9.673317390-01	2.824917620-02	9.934383060-01	1.005919763-00	-8.850362410-04
-9.816716590-02	-7.587092060-01	7.587094180-01	0.0	1.658709420-02	-5.662913380-00	1.006118920-00	0.0
-3.495828890-08	-1.429000980-02	3.840250440-07	4.084347130-01	-1.501755770-01	-1.453723040-01	3.796095180-08	4.588079630-01
1.912533690-01	1.893708290-01	1.912533690-01	1.893708290-01	2.710054390-01	-1.847243120-01	3.796095180-08	4.588079630-01
-3.797058240-07	3.398198320-08	-1.648760240-08	-2.4417045180-01	-3.8933010820-01	2.295556570-00	3.796095180-08	4.588079630-01

## GIACOB-ZIN(1985)

## END OF TRAJECTORY SEGMENT 1, THRUST OFF

1.892200000-02	9.966431370-01	9.877358070-02	1.012293300-01	3.458709420-02	2.925690260-01	1.031830110-00	2.092569030-02
9.960727880-01	2.692797310-01	8.909602210-04	-1.651044053-01	9.527190150-01	1.551126430-03	1.000000000-00	1.619452160-02
8.905341390-02	5.195455710-02	2.915005070-04	7.030975570-02	-5.991054940-02	-1.245993590-04	1.000000000-00	-2.479404690-02
0.0	0.0	0.0	9.010628970-01	7.627306110-01	9.934383060-01	9.603559020-01	-9.153409050-04
9.118137630-02	1.513198430-01	1.513225260-01	4.947351940-02	1.512790630-01	5.296205880-01	0.0	0.0
-1.634932600-01	-2.387458100-01	-1.407311070-01	5.033225320-01	-1.392004540-01	1.519020970-01	3.217683210-01	2.060510690-01
-1.638502370-01	-1.826888580-01	1.511060130-01	1.339544910-01	8.832212590-01	4.745291770-01	3.217683210-01	2.060510690-01
-8.552795700-00	-3.101268090-01	6.4417390670-01	1.558600060-00	-3.520454280-00	2.024222310-01	3.217683210-01	2.060510690-01

## GIACOB-ZIN(1985)

## START OF TRAJECTORY SEGMENT 2, THRUST OFF

1.892200000-02	9.966431370-01	9.877358070-02	1.012293300-01	3.458709420-02	2.925690260-01	1.031830110-00	2.092569030-02
9.960727880-01	2.692797310-01	8.909602210-04	-1.651044053-01	9.527190150-01	1.551126430-03	1.000000000-00	1.619452160-02
8.905341390-02	5.195455710-02	2.915005070-04	7.030975570-02	-5.991054940-02	-1.245993590-04	1.000000000-00	-2.479404690-02
0.0	0.0	0.0	9.010628970-01	7.627306110-01	9.934383060-01	9.603559020-01	-9.153409050-04
9.118137630-02	1.513198430-01	1.513225260-01	4.947351940-02	1.512790630-01	5.296205880-01	0.0	0.0
-1.208744450-07	6.818518530-07	1.332867580-05	-9.826659340-00	-2.696773230-00	4.649802060-02	6.924841930-07	1.018745010-01
1.573990770-01	1.334140520-01	-1.000000000-00	-1.000000000-00	1.647059360-02	2.615128950-01	6.924841930-07	1.018745010-01
1.2492339290-06	6.923702200-07	1.332867580-05	-1.015991260-01	-7.470707320-01	4.649802060-02	6.924841930-07	1.018745010-01

## DEEP SPACE BURN

188.9 METERS/SECOND AT 199.22 DAYS

## EARTH

## END OF TRAJECTORY, THRUST OFF

3.680000000-02	9.966431370-01	9.877358070-02	1.012293300-01	3.458709420-02	1.800000000-02	9.923389820-01	0.0
-9.734610710-01	1.957986300-01	5.664450510-08	-9.543430530-02	-1.001842980-00	-1.885530520-03	1.000000000-00	1.701477440-02
4.423972260-02	5.726471970-01	9.086427640-04	-4.716424170-01	9.017742720-02	-1.065931000-05	1.000000000-00	-2.520507910-02
0.0	0.0	0.0	9.612970400-01	2.827036970-02	9.934383060-01	1.005919763-00	-8.850362410-04
-1.648836890-02	-8.304507040-01	8.304507070-01	3.2688511270-06	1.696274650-02	-5.931020270-00	1.006379950-00	0.0
9.370437850-02	-4.494823190-03	8.473961320-00	-3.4551054220-00	-1.776539290-01	-5.618036930-02	4.591465820-03	3.555938830-00
-4.526972090-00	-7.580240210-00	-1.000000000-00	-1.000000000-00	1.769965160-02	-9.049328670-01	4.591465820-03	3.555938830-00
-3.246200580-01	4.591343250-03	8.473961320-00	3.516379190-00	-5.259509980-01	-5.618036930-02	4.591465820-03	3.555938830-00

## CASE 1

## ITERATOR SUMMARY

## INDEPENDENT PARAMETERS

```

1.PRIM1( 0.0 ) ) 2.PRIM2( 1.00000000-01) 3.PRIM3( 0.0 ) ) 4.PDOT1( 0.0 ) ) 5.PDOT2( 0.0 ) )
6.PDOT3( 0.0 ) ) 7.LMASS( 1.00000000 00) 8.LTAD(-1.00000000D 03) ) 9. ) 10.DECLN( 0.0 ) )
11.ACCEL( 1.00000000-04) 12.V JET( 1.00000000 00) 13.VINF1( 0.0 ) ) 14.VINF2( 0.0 ) ) 15.TIME1(-1.50000000 01)
16.TIME2( 3.53000000 02) 17.PARK( 0.0 ) ) 18.VE-31(-1.08125070-01) 19.VE-32(-9.95153750-01) 20.VELO3(-1.76892320-03)
21.THE1( 0.0 ) ) 22.THE2( 0.0 ) ) 23.THE3( 0.0 ) ) 24.THE4( 0.0 ) ) 25.THE5( 0.0 ) )
26.THE7( 0.0 ) ) 27.THE7( 0.0 ) ) 28.THE7( 0.0 ) ) 29.THE7( 0.0 ) ) 30.LDEGR( 0.0 ) )
31.PHI1( 0.0 ) ) 32.PHI2( 0.0 ) ) 33.PHI3( 0.0 ) ) 34.PHI4( 0.0 ) ) 35.PHI5( 0.0 ) )
36.PHI6( 0.0 ) ) 37.PHI7( 0.0 ) ) 38.PHI8( 0.0 ) ) 39.PHI9( 0.0 ) ) 40.PHI10( 0.0 ) )
41.PRI-A( 8.20534140-02) 42.PRI-A( 5.19545570-02) 43.PRI-A( 2.91500510-04) 44.PRI-A( 7.03097560-02) 45.PRI-A(-5.99105490-02)
46.PRI-A(-1.29999360-04) 47.VINF1( 0.0 ) ) 48.VINF2( 0.0 ) ) 49.VINF3( 0.0 ) ) 50.VINF4( 0.0 ) )
51.PRI-B( 0.0 ) ) 52.PRI-B( 0.0 ) ) 53.PRI-B( 0.0 ) ) 54.PRI-B( 0.0 ) ) 55.PRI-B( 0.0 ) )
56.PRI-B( 0.0 ) ) 57.VINF3( 0.0 ) ) 58.VINF4( 0.0 ) ) 59.VINF5( 0.0 ) ) 60.VINF6( 0.0 ) )
61.PRI-C( 0.0 ) ) 62.PRI-C( 0.0 ) ) 63.PRI-C( 0.0 ) ) 64.PRI-C( 5.57343290-03) 65.PRI-C( 3.03094120-03)
66.PRI-C( 1.46433320-04) 67.VINF1( 0.0 ) ) 68.VINF2( 0.0 ) ) 69.VINF3( 0.0 ) ) 70.VINF4( 0.0 ) )

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## DEPENDENT PARAMETERS

```

1.DELTA X(-2.169930-07) 2.DELTA Y( 3.069100-05) 3.DELTA Z( 5.664450-08) 4. ) 5. ) ( 0.0 ) )
6. ) ( 0.0 ) ) 7. ) ( 0.0 ) ) 8. ) ( 0.0 ) ) 9. ) ( 0.0 ) )
11. ) ( 0.0 ) ) 12. ) ( 0.0 ) ) 13. ) ( 0.0 ) ) 14. ) ( 0.0 ) ) 15. ) ( 0.0 ) )
16. ) ( 0.0 ) ) 17. ) ( 0.0 ) ) 18. ) ( 0.0 ) ) 19. ) ( 0.0 ) ) 20. ) ( 0.0 ) )
21. ) ( 0.0 ) ) 22. ) ( 0.0 ) ) 23. ) ( 0.0 ) ) 24. ) ( 0.0 ) ) 25. ) ( 0.0 ) )
26. ) ( 0.0 ) ) 27. ) ( 0.0 ) ) 28. ) ( 0.0 ) ) 29. ) ( 0.0 ) ) 30. ) ( 0.0 ) )
31. ) ( 0.0 ) ) 32. ) ( 0.0 ) ) 33. ) ( 0.0 ) ) 34. ) ( 0.0 ) ) 35. ) ( 0.0 ) )
36. ) ( 0.0 ) ) 37. ) ( 0.0 ) ) 38. ) ( 0.0 ) ) 39. ) ( 0.0 ) ) 40. ) ( 0.0 ) )
41.DEL X A(-5.717150-08) 42.DEL Y A(-2.073050-07) 43.DEL Z A( 4.289730-09) 44. ) 45. ) ( 0.0 ) )
46. ) ( 0.0 ) ) 47. ) ( 0.0 ) ) 48. ) ( 0.0 ) ) 49. ) ( 0.0 ) ) 50. ) ( 0.0 ) )
51. ) ( 0.0 ) ) 52. ) ( 0.0 ) ) 53. ) ( 0.0 ) ) 54. ) ( 0.0 ) ) 55. ) ( 0.0 ) )
56. ) ( 0.0 ) ) 57. ) ( 0.0 ) ) 58. ) ( 0.0 ) ) 59. ) ( 0.0 ) ) 60. ) ( 0.0 ) )
61. ) ( 0.0 ) ) 62. ) ( 0.0 ) ) 63. ) ( 0.0 ) ) 64. ) ( 0.0 ) ) 65. ) ( 0.0 ) )
66. ) ( 0.0 ) ) 67. ) ( 0.0 ) ) 68. ) ( 0.0 ) ) 69. ) ( 0.0 ) ) 70. ) ( 0.0 ) )

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## THRUST SWITCHING TIMES (DAYS)

OFF 189.220 VISIT 199.220 ON 368.000 OFF

## POWER

18175.6839354431

## EFFICIENCY

0.0000000045

## ELECTRIC PROPULSION PARAMETERS

PROP TIME J

0.0

## PROP TIME RATIO

0.0

## AVE ACCEL

0.0001000000

## INITIAL

1634.7360602603

## PROPULSION

0.0

## MASS COMPONENT BREAKDOWN

PROPELLANT TANKAGE

0.0

## STRUCTURE

0.0

## PAYLOAD

1634.7360602603

## SWITCH-COUNT HISTORY ALL 5

0 THRUST COMPUTE STEPS. 52 COAST COMPUTE STEPS

## CASE 1

## EXTREMUM POINTS OF SELECTED FUNCTIONS

I	TIME	ECLIPTIC LONGITUDE	SOLAR DISTANCE	COMMUNICATION ANGLE	SWITCH FUNCTION	THRUST ANGLES PSI	THRUST ANGLES THETA	PHI	INPUT POWER	ARRAY ANGLE
0	0.0	0.0	0.992	3.4	OFF -8.95D 04	*****	*****	*****	0.0	ON 90.0
4	82.559	93.1	0.898	54.6	-8.17D 04	*****	*****	*****	0.0	90.0
5	179.513	200.2	1.016	77.6	MAX -9.03D 04	*****	*****	*****	0.0	90.0
4	189.220	209.3	1.032	79.9	OFF -9.15D 04	*****	*****	*****	0.0	90.0
0	189.220	209.3	1.032	79.9	OFF -9.15D 04	*****	*****	*****	0.0	90.0
4	199.220	218.3	1.047	82.5	OFF -9.27D 04	*****	*****	*****	0.0	90.0
4	267.702	275.6	1.102	106.2	MAX -9.72D 04	*****	*****	*****	0.0	90.0
4	368.000	362.8	0.993	101.8	OFF -8.35D 04	*****	*****	*****	0.0	ON 90.0

## CASE 1

## MISSION SCHEDULE

-----MARCH 6, 1985 1.200000000 01-G.M.I.4  
 2456131.0000 00 JULIAN DATE

PLANET -9.6222210D-01 2.4221234D-01 0.0  
 S/C -9.6222210D-01 2.4221234D-01 0.0

DEPART EARTH  
 XDOT YDOT ZDOT  
 -2.6345355D-01 -9.7355492D-01 0.0  
 -1.4812517D-01 -9.9515375D-01 -1.7689232D-03  
 RADIUS 9.9223898D-01  
 LAT. 0.0  
 LONG. 165.871

-----SEPTEMBER 11, 1985 1.728000000 01-G.M.I.4  
 2456320.2200 00 JULIAN DATE

PLANET 9.8607285D-01 2.6927994D-01 8.9095593D-04  
 S/C 9.8607279D-01 2.6927973D-01 8.9096022D-04

DEPART EARTH  
 XDOT YDOT ZDOT  
 -2.1713321D-01 1.0709149D 00 -6.7335209D-01  
 -1.6510411D-01 9.5271901D-01 1.5511264D-03  
 RADIUS 1.0318302D 00  
 LAT. 0.049  
 LONG. 15.129

TWO-BODY TRANSFER ANGLE BETWEEN EARTH AND GIACOB-ZIN(1985) IS 209.2569 DEGREES.

-----MARCH 2, 1986 1.200000000 01-G.M.I.4  
 2456492.0000 00 JULIAN DATE

PLANET -9.7346085D-01 1.9576794D-01 0.0  
 S/C -9.7346107D-01 1.9579863D-01 5.6644505D-08

DEPART EARTH  
 XDOT YDOT ZDOT  
 -2.1319335D-01 -9.8418468D-01 0.0  
 -9.5434350D-02 -1.0018430D 00 -1.8955305D-03  
 RADIUS 9.9295071D-01  
 LAT. 0.0  
 LONG. 168.629

TWO-BODY TRANSFER ANGLE BETWEEN EARTH AND IS 2.7583 DEGREES.

CASE 1 (CONVERGED)

PERFORMANCE SUMMARY

EARTH TO EARTH FLYBY

WITH VISITATION OF GIACOB-ZIN(1985)

LAUNCH VEHICLE IS ATLAS(SLV3X1)/CENTAUR

(COEFFICIENTS = 77360.1300 3652.7918 1653.7180)

LO = MAR 6. 1985. 12.0000 HOURS GMT  
JULIAN DATE 46131.0000

AD = MAR 9. 1986. 12.0000 HOURS GMT  
JULIAN DATE 46499.0000

FLIGHT TIME = 368.0000 DAYS.

ELECTRIC PROPULSION SYSTEM PARAMETERS

ALPHA A (KG/KW)	0.0	ALPHA T (KG/KW)	0.0	TANKAGE FACTOR	0.0300	STRUCTURE FACTOR	0.0	EFFICIENCY COEFFICIENTS	
								B	
								D (KM/SEC)	E
								0.76000	13.00000
									0.0

ELECTRIC PROPULSION SYSTEM MASS SUMMARY (KG)

INITIAL	1634.7361	POWER PLANT	0.0	PROPELLANT	0.0	TANKAGE	0.0	STRUCTURE	0.0	NET MASS	1634.7361
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ELECTRIC PROPULSION SYSTEM PERFORMANCE SUMMARY

P(1 AU) (KW)	18175.6839	P(HSKP) (KW)	0.0	P(TARG) (KW)	18339.2277	THR(1 AU) (N)	0.163474	ACC(1 AU) (M/SEC**2)	1.0000000-04	ISP (SEC)	0.102	EFFIC	0.00000	CHAR DEG (DAYS)	1.00000000 30
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EXTREME TRAJECTORY AND PERFORMANCE CONDITIONS

MAX DIST (AU)	1.1019581	MIN DIST (AU)	0.8982011	MAX POWER (KW)	0.0	MAX THRUST (N)	0.0	BURN TIME (DAYS)	0.0	DEGRD TIME (DAYS)	0.0	TRAV ANG (DEG)	362.75652
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DEPARTURE AND ARRIVAL CONDITIONS

DEP DECL (DEG)	-5.1246	PARK INC (DEG)	28.5000	DEP VINP (M/SEC)	3407.29049	C3 (KM**2/SEC**2)	11.609629	ARR VINP (M/SEC)	3555.93883	C4 (KM**2/SEC**2)	12.644701
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# SWINGBY CONTINUATION ANALYSIS

THIS CASE IS CONVERGED.

11 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND 4 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

		EARTH		SWINGBY CONTINUATION TO EARTH			
PASS DIST (RADII)	SPEED (M/SEC)	INCLIN (DEG)	NODE (DEG)	ARG PER (DEG)	LEG TIME (DAYS)	MISSION TIME (DAYS)	ARR VINP (M/SEC)
60.0441	3837.49	162.1881	185.7729	109.232	527.95	895.95	3557.35
ARRIVAL V00 =	1.18059057D-01	-1.76583002D-02	-1.88553052D-03	MAG =	1.19387235D-01	(ECLIPTIC REFERENCE SYSTEM)	
DEPARTURE V00 =	1.14058254D-01	-3.52707853D-02	5.00585922D-07	MAG =	1.19387242D-01	(ECLIPTIC REFERENCE SYSTEM)	
ARRIVAL V00 =	9.88875047D-01	-1.47907774D-01	-1.57934011D-02	MAG =	1.00000000D 00	(ECLIPTIC REFERENCE SYSTEM)	
DEPARTURE V00 =	9.55363839D-01	-2.95431779D-01	4.19296052D-05	MAG =	1.00000000D 00	(ECLIPTIC REFERENCE SYSTEM)	
HELIOCENTRIC APPROACH ANGLE = 177.0, DEPART ANGLE = 174.2, BEND ANGLE = 8.7 DEGREES.							
SWINGBY INCLINATION W.R.T. ECLIPTIC = -6.0 DEGREES.							

POWERED SWINGBY INCREMENTAL SPEED = 0.0 METERS/SECOND. BEND ANGLE = 8.7 DEGREES. (PLANETOCENTRIC)

POWERED SWINGBY ANALYSIS ONLY, FOR FIXED SWINGBY LEG FLIGHT TIME 127.0 DAYS.

THIS CASE IS CONVERGED.

5 TRAJECTORIES WITHOUT PARTIAL DERIVATIVES AND 2 TRAJECTORIES WITH PARTIAL DERIVATIVES REQUIRED FOR THIS CASE.

		EARTH		SWINGBY CONTINUATION TO BORRELLY(1987)			
PASS DIST (RADII)	SPEED (M/SEC)	INCLIN (DEG)	NODE (DEG)	ARG PER (DEG)	LEG TIME (DAYS)	MISSION TIME (DAYS)	ARR VINP (M/SEC)
3.3636	7057.96	15.9836	15.8632	263.592	127.00	1022.95	17349.74
ARRIVAL V00 =	1.05096419D-01	-5.67395634D-02	-4.65529662D-07	MAG =	1.19433649D-01	(ECLIPTIC REFERENCE SYSTEM)	
DEPARTURE V00 =	8.32614018D-02	8.24040853D-02	-1.79817708D-02	MAG =	1.18516814D-01	(ECLIPTIC REFERENCE SYSTEM)	
ARRIVAL V00 =	8.79949161D-01	-4.75067862D-01	-3.89777727D-05	MAG =	1.00000000D 00	(ECLIPTIC REFERENCE SYSTEM)	
DEPARTURE V00 =	7.02528184D-01	6.95294303D-01	-1.51723371D-01	MAG =	1.00000000D 00	(ECLIPTIC REFERENCE SYSTEM)	
HELIOCENTRIC APPROACH ANGLE = 5.7, DEPART ANGLE = 78.9, BEND ANGLE = 73.3 DEGREES.							
SWINGBY INCLINATION W.R.T. ECLIPTIC = 9.1 DEGREES.							

POWERED SWINGBY INCREMENTAL SPEED = -13.7 METERS/SECOND. BEND ANGLE = 73.3 DEGREES. (PLANETOCENTRIC)

DETAILED PRINT OF POST-SWINGBY TRAJECTORY SEGMENT TO EARTH

FOR SOLUTION HAVING 60.04 PASSAGE DISTANCE

TIME	SEMI-MAJOR AXIS				ECCENTRICITY				INCLINATION				NODE				ARG POS				RMAG				TRAVEL			
	R1	R2	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20	L21	L22	L23	L24	L25	L26
PSI																												
R1 REL																												
S/C NUC MAG																												
R1 REL ECL																												
R2 REL																												
S/C TOT MAG																												
R2 REL ECL																												
R3 REL																												
GEO NUC MAG																												
R3 REL ECL																												
THETA																												
R2 REL																												
PHI																												
R3 REL																												
CONE																												
LATITUDE																												
V1 REL																												
SEO TOT MAG																												
V1 REL ECL																												
V2 REL																												
ANG(V,R)																												
V2 REL ECL																												
ANG(V,XY)																												
V3 REL																												
V3 REL ECL																												
RMAG ECL																												
POWER FNCT																												
VMAG																												
RMAG REL																												
VMAG REL																												
FLY PTH ANGLE																												
VMAG ECL																												
THRUST ACC																												
HAM																												
PROP TIME																												
VMAG REL																												
VMAG ECL																												

PAGE 2

EARTH

START OF TRAJECTORY SEGMENT 3, THRUST OFF

3.68000000 02	1.036259580 00	1.093004390 01	2.865711310 05	1.799999910 02	3.496274740 02	9.929569780 01	3.627565180 02
-9.734610710 01	1.957986300 01	5.664450510 08	-9.943510390 02	-1.019455460 00	5.005359920 07	1.000000000 00	1.701477440 02
4.423972260 02	5.726471970 01	9.086427640 04	-4.716428170 01	9.017742720 02	-1.065531000 05	1.000000000 00	-2.550375910 02
0.0	0.0	0.0	9.612979400 01	2.827036970 02	1.011559460 00	1.008997940 00	-3.566158740 04
9.067126560 02	-8.304506190 01	8.304507070 01	3.268511270 06	1.686274650 02	-5.801671430 00	1.024293310 00	0.0
9.370437850 02	-4.494823190 03	8.473961320 00	-3.537653570 00	3.601299000 01	1.490991200 05	4.591465820 03	3.555939050 00
-4.526972090 00	-7.580248210 00	-1.000000000 30	-1.000000000 30	1.741873710 02	2.402389420 04	4.591465820 03	3.555939050 00
-3.246200580 01	4.591343250 03	8.473961320 00	3.397215590 00	-1.050537400 00	1.4930991200 05	4.591465820 03	3.555939050 00

EARTH

END OF TRAJECTORY, THRUST OFF

8.959458970 02	1.036259580 00	1.093004390 01	2.865711310 05	1.799999910 02	1.459345130 02	1.012050770 00	8.800635580 02
8.383806430 01	-5.668903470 01	1.407953980 07	6.490089110 01	7.680909400 01	-4.655236600 07	1.000000000 00	1.660659590 02
-5.765927250 01	-7.098020000 01	-8.220367550 04	8.094332940 01	-5.499732690 01	-5.163421370 04	1.000000000 00	-2.550375910 02
0.0	0.0	0.0	7.942840590 01	2.605688390 02	1.011869460 00	9.847924370 01	-3.500570580 04
-5.153042720 02	-9.502245990 01	9.502245790 01	7.970926230 06	-3.406349570 01	6.131398520 00	1.005572600 00	0.0
3.769626320 01	-7.023045200 00	2.106285070 01	3.539751350 00	3.534317340 01	-1.386576210 05	4.374900120 01	3.557351060 00
-1.315872610 01	-1.764379180 01	-1.000000000 30	-1.000000000 30	5.701784440 00	-2.233251870 04	4.374900120 01	3.557351060 00
2.729361300 01	-2.693306730 01	2.106285070 01	3.130288090 00	-1.6890933170 00	-1.386576210 05	4.374900120 01	3.557351060 00

## CASE 1

## EXTREMUM POINTS OF SELECTED FUNCTIONS

I	TIME	ECLIPTIC LONGITUDE	SOLAR DISTANCE	COMMUNICATION ANGLE	DISTANCE	SWITCH FUNCTION	PSI	THRUST ANGLES THETA	PHI	INPUT POWER	ARRAY ANGLE
0	0.0	0.0	0.992	3.4	0.0	OFF	0.0	0.0	0.0	0.0	ON
4	82.559	93.1	0.998	54.6	0.23	OFF	0.0	0.0	0.0	0.0	0.0
5	179.513	200.2	1.016	77.6	MAX	OFF	0.0	0.0	0.0	0.0	0.0
4	189.220	209.3	1.032	79.9	0.46	OFF	0.0	0.0	0.0	0.0	0.0
0	189.220	209.3	1.032	79.9	0.46	OFF	0.0	0.0	0.0	0.0	0.0
4	199.220	218.3	1.047	82.5	0.45	OFF	0.0	0.0	0.0	0.0	0.0
4	267.702	275.6	1.102	106.2	0.29	OFF	0.0	0.0	0.0	0.0	0.0
4	368.000	362.8	0.993	101.8	0.30	OFF	0.0	0.0	0.0	0.0	ON
0	368.000	362.8	0.993	101.8	0.00	OFF	0.0	0.0	0.0	0.0	0.0
4	368.005	362.8	0.993	84.2	MIN	OFF	0.0	0.0	0.0	0.0	0.0
4	434.075	436.2	0.923	54.6	0.17	OFF	0.0	0.0	0.0	0.0	0.0
5	521.214	530.2	1.032	83.4	MAX	OFF	0.0	0.0	0.0	0.0	0.0
4	626.726	616.2	1.150	169.8	0.34	OFF	0.0	0.0	0.0	0.0	0.0
9	632.049	620.2	1.149	179.5	MIN	OFF	0.0	0.0	0.0	0.0	0.0
7	632.345	620.4	1.149	180.0	0.16	OFF	0.0	0.0	0.0	0.0	0.0
5	742.568	712.1	1.012	82.8	MAX	OFF	0.0	0.0	0.0	0.0	0.0
4	819.377	796.2	0.923	57.9	0.20	OFF	0.0	0.0	0.0	0.0	0.0
3	895.946	880.1	1.012	92.6	MIN	OFF	0.0	0.0	0.0	0.0	0.0
4	895.946	880.1	1.012	149.5	0.00	OFF	0.0	0.0	0.0	0.0	ON

-----AUGUST 12, 1987, 1.070151880 01.6 M.T.  
-----2447026.9460 00 JULIAN DATE

PASS EARTH AT 3.557 K4/SEC

X	Y	Z	PASS	EARTH	YDOT	ZDOT	RADIUS	LAT.	LONG.
PLANET	8.3838046D-01	-5.6689017D-01	0.0	5.4391213D-01	8.2493050D-01	0.0	1.0120505D 00	0.0	-34.065
S/C	8.3838046D-01	-5.6689035D-01	1.4079540D-07	6.4900991D-01	7.6809094D-01	-4.6552966D-07	1.0120505D 00	0.000	-34.065

TWO-BODY TRANSFER ANGLE BETWEEN EARTH AND EARTH IS 160.0636 DEGREES.

DETAILED PRINT OF POST-SWINGBY TRAJECTORY SEGMENT TO BORRELLY(1987)

FOR SOLUTION HAVING 3.36 PASSAGE DISTANCE

PAGE 3

TIME	SEMI-MAJOR AXIS	ECCENTRICITY	INCLINATION	NODE	ARG POS	RMAG	MASS RATIO	TRAVEL
R1	R2	R3	V1	V2	V3	L7	POWER FNCT	THRUST ACC
L1	L2	L3	L4	L5	L6	L7	VMAG	HAM
LG	LC	LPHI	CONC	CLOCK	HMAC	VMAG	PROP TIME	SWITCH FNCT
PS1	THETA	PHI	LATITUDE	LONGITUDE	-FLT PTH ANGLE	RMAG REL	VMAG REL	
R1 REL	R2 REL	R3 REL	V1 REL	V2 REL	V3 REL	RMAG ECL	VMAG ECL	
S/C NUC MAG	S/C TOT MAG	GEO NUC MAG	GEO TOT MAG	ANG(V,R)	ANG(V,XY)			
R1 REL ECL	R2 REL ECL	R3 REL ECL	V1 REL ECL	V2 REL ECL	V3 REL ECL			

EARTH

START OF TRAJECTORY SEGMENT 4, THRUST OFF

8.95945897D 02	1.31675896D 00	2.31624927D-01	9.34109222D-01	1.45934993D 02	1.79999511D 02	1.01205077D 00	8.00063558D 02	
8.3838043D-01	-5.66890347D-01	1.40795398D-07	6.27173891D-01	9.07234569D-01	-1.79817708D-02	1.00000000D 00	1.66065959D-02	
-5.76592725D-01	-7.09802000D-01	-8.22036755D-04	8.09433294D-01	-5.48973269D-01	-5.16342137D-04	1.00000000D 00	6.95470793D-02	
0.0	0.0	0.0	7.94284059D 01	2.60568939D 02	1.11629508D 00	9.84792437D-01	-3.58057058D 04	
-9.82025299D-01	-9.50231976D 01	9.50224579D 01	7.97032523D-06	-3.40654957D 01	5.90643552D-01	1.10306165D 00	0.0	
-1.69367987D 08	-6.70264746D 07	7.21319315D 07	2.63030952D 01	5.91323267D 00	5.18989117D 00	1.95910895D 08	2.74545826D 01	
1.73856513D 01	1.69804738D 01	1.73856509D 01	1.69804738D 01	1.68528869D 01	1.08965033D 01	1.95910895D 08	2.74545826D 01	
-1.19906972D 08	-6.18246515D 07	1.42144577D 08	2.60983123D 01	3.05278047D 00	-8.24635270D 03	1.95910895D 08	2.74545826D 01	

BORRELLY(1987)

END OF TRAJECTORY, THRUST OFF

1.02294590D 03	1.31675896D 00	2.31624927D-01	9.34109222D-01	1.45934993D 02	2.87810226D 02	1.35864643D 00	9.87874273D 02	
3.80201236D-01	1.30419417D 00	-2.10878993D-02	-7.34535522D-01	4.15015951D-01	1.08930263D-03	1.00000000D 00	1.09773500D-02	
8.11785347D-01	-4.19648936D-01	4.26549064D-03	2.10373153D-01	4.35492117D-01	5.25235184D-03	1.00000000D 00	6.85470793D-02	
0.0	0.0	0.0	1.03022942D 02	2.62522979D 02	1.11629508D 00	6.46819844D-01	-3.89521325D 04	
7.6840369D-01	-1.01086943D 02	1.01086701D 02	-8.89330181D-01	7.37474369D 01	1.33703596D 01	8.44164020D-01	0.0	
4.8651881D 00	-9.59694915D 00	-2.09227858D 00	4.70047212D 00	-1.13557788D 01	-1.22460387D 01	1.09612553D 01	1.73497439D 01	
-1.70193101D 01	-2.00098098D 01	1.48530167D 01	1.42706208D 01	7.42807077D 01	-4.48969591D 01	1.09612553D 01	1.73497439D 01	
8.27254599D 00	2.54795529D 00	-6.72473244D 00	4.72217933D 00	3.25534561D 00	-1.63742896D 01	1.09612553D 01	1.73497439D 01	



CASE 1

EXTREMUM POINTS OF SELECTED FUNCTIONS

1	TIME	ECLIPTIC LONGITUDE	SOLAR DISTANCE	COMMUNICATION ANGLE	SWITCH FUNCTION	PSI	THRUST ANGLES THETA	PHI	INPUT POWER	ARRAY ANGLE
0	0.0	0.0	0.992	3.4	OFF -8.050 04	*****	*****	*****	0.0	ON 90.0
4	82.559	93.1	0.898	54.6	-8.190 04	*****	*****	*****	0.0	90.0
5	179.513	200.2	1.016	77.6	-9.020 04	*****	*****	*****	0.0	90.0
4	189.220	209.3	1.032	79.9	OFF -9.150 04	*****	*****	*****	0.0	90.0
0	189.220	209.3	1.032	79.9	OFF -9.150 04	*****	*****	*****	0.0	90.0
4	199.220	219.3	1.047	82.5	OFF -9.270 04	*****	*****	*****	0.0	90.0
4	267.702	275.6	1.102	106.2	-9.720 04	*****	*****	*****	0.0	90.0
4	368.000	362.8	0.993	101.8	OFF -8.350 04	*****	*****	*****	0.0	ON 90.0
0	368.000	362.8	0.993	101.8	OFF -8.350 04	*****	*****	*****	0.0	90.0
4	368.005	362.8	0.993	84.2	-3.570 04	*****	*****	*****	0.0	90.0
4	434.075	436.2	0.923	54.6	-3.520 04	*****	*****	*****	0.0	90.0
5	521.214	530.2	1.032	83.4	-3.500 04	*****	*****	*****	0.0	90.0
4	626.726	616.2	1.150	169.8	-3.590 04	*****	*****	*****	0.0	90.0
9	632.049	620.2	1.149	179.5	-3.590 04	*****	*****	*****	0.0	90.0
7	632.345	620.4	1.149	MAX 180.0	-3.590 04	*****	*****	*****	0.0	90.0
5	742.568	712.1	1.012	82.8	-3.590 04	*****	*****	*****	0.0	90.0
4	819.377	796.2	0.923	57.9	-3.520 04	*****	*****	*****	0.0	90.0
3	895.946	890.1	1.012	92.6	-3.580 04	*****	*****	*****	0.0	90.0
4	895.946	880.1	1.012	149.5	OFF -3.590 04	*****	*****	*****	0.0	ON 90.0
0	895.946	880.1	1.012	149.5	OFF -3.590 04	*****	*****	*****	0.0	90.0
7	895.946	880.1	1.012	151.1	-3.530 04	*****	*****	*****	0.0	90.0
8	963.191	945.8	1.150	MAX 173.7	-3.590 04	*****	*****	*****	0.0	90.0
4	1022.946	987.9	1.359	125.6	OFF -3.900 04	*****	*****	*****	0.0	ON 90.0

DECEMBER 24, 1987 1.070151890-01 G.M.T.  
 2447153.9360 00 JULIAN DATE

PASS BORRELLY(1987) AT 17.350 KM/SEC

X	Y	Z	XDOT	YDOT	ZDOT	RADIUS	LAT.	LONG.
PLANET 3.80201180-01	1.30419420 00	-2.10878540-02	-8.93373160-01	3.05720850-01	5.50840370-01	1.35864640 00	-0.889	73.747
S/C 3.80201240-01	1.30415420 00	-2.10878990-02	-7.34335520-01	4.16015950-01	1.08730260-03	1.35864640 00	-0.889	73.747

TWO-BODY TRANSFER ANGLE BETWEEN EARTH AND BORRELLY(1987) IS 267.8768 DEGREES.

V. REFERENCES

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- [3] J. L. Horsewood, F.I. Mann and K.B. Brice, "The Generation and Interpretation of Electric Propulsion Mission Analysis Data," AMA, Inc. Report No. 73-38, August 1973.
- [4] Jerry L. Horsewood and F.I. Mann, "The Optimization of Low Thrust Heliocentric Trajectories with Large Launch Asymptote Declinations," AIAA Paper No. 74-803, Presented at the AIAA Mechanics and Control of Flight Conference, Anaheim, California, August 5-9, 1974.
- [5] "Launch Vehicles Estimating Factors," NASA Office of Space Science, 1973 Edition.
- [6] P. Gunther, "Asymptotically Optimum Two-Impulse Transfer from Lunar Orbit," AIAA Journal, Vol. 4, No. 2, pp. 346-349, February 1966.